EVERYDAY SCIENCE

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EVERYDAY SCIENCE

A COURSE OF GENERAL SCIENCE RELATED TO HUMAN ACTIVITIES

BY

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PART II. PHYSICS

MAN'S USE OF MOTION

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PREFACE

FOR several years there has been an active movement in educational circles in favour of extending the scope of the science courses usually followed in Secondary Schools. The view held by competent authorities is expressed in three resolutions adopted by the Headmasters' Conference some time ago, namely:

(1) That it is essential to a boy's general education that he should have some knowledge of the natural laws underlying the phenomena of daily life, and some training in their experimental investigation.

(2) That this can best be ensured by giving to all boys adequate courses of generalised science work, which would normally be completed for the ordinary boy at the age of sixteen.

(3) That, after this stage, boys who require it should take up science work of a more specialised type, while the others should for some time continue to do some science work of a more general character.

Though these principles would be accepted as axiomatic by most educationists, it is to be regretted that they have not yet been put into practice in many schools. A Report on Science in School Certificate Examinations just published by the British Association shows that out of about 54,000 candidates who sat for the School Certificate Examination in 1926, 40 per cent. took chemistry as their science subject, 25 per cent. took physics, and 25 per cent. (chiefly girls) botany, while only 2·5 per cent. took general science. As about 3 per cent. only of these candidates propose to proceed to a University or qualify for a subsequent professional examination, and most of the remaining 97 per cent. receive no further education in science, it is evident that the usual courses followed in schools are not adapted to the everyday life and interests of the majority of the pupils, but to the academic requirements of the minority.

No school course in science can be regarded as complete or satisfactory if it neglects the interests of pupils in the natural world of living creatures around them and their own relations to the life of the community. Even to read newspaper reports of natural events and phenomena intelligently requires a general knowledge of things in the heavens above and the earth beneath, of common plants and animals, of life as a whole, including man and his mastery of Nature. It is with the purpose of providing such a survey of the natural world in which we live and our relation to it that this book has been written.

The general plan of the book conforms to the syllabuses of general or everyday science of the Oxford and Cambridge Schools Examination Board, the Oxford Local Examinations and the Civil Service Commissioners. A syllabus of General Science of School Certificate standard has just been included in the Cambridge Local Examinations schedules, and most of the subjects in this syllabus are dealt with descriptively in this book. The Cambridge syllabus, however, seems scarcely to have been conceived in the spirit of general everyday science for all, but is rather a combination of introductory courses of physics, chemistry, botany, and other subjects of the usual systematic kind.

An attempt is made in this volume to give a broad general survey of the realm of science suitable for use in schools, whether examinations are the proximate or ultimate aim of the teaching or not. Particular attention has been given to contacts of scientific work and results with everyday life, because it is through these that interest is best created in any subject. For this reason the book may appeal to the general reader who desires information upon common natural occurrences and phenomena brought before him from time to time, or wishes to obtain a general idea of everyday applications of science, as much as to the student preparing for an examination in general elementary science.

The subject matter ranges from a description of the vast objects of celestial space to that of the minute structure of the atom. The Universe, Life, and Man are first described, and then an elementary account of man's dealings with objects in

motion and his relations with matter is given. The subjects dealt with can be studied in schools as a progressive course extending over three years, but in order that the book may be equally suitable to the requirements of those teachers who wish to concentrate on certain sections of the subject matter, three separate Parts of the book are available, namely :

Part I dealing with astronomy, geology, and biology.

Part II dealing with elementary physics.

Part III dealing with elementary chemistry.

The Parts may be studied in any order, but in at least one of them the pupil should carry out experimental work. In each Part there are brief historical notes dealing with the progress of scientific discovery, and also references of a biographical character, as well as a set of typical examination questions, many of them from papers set by the Civil Service Commission, the Oxford and Cambridge Schools Examination Board, and other public examining bodies. Thanks are due to those authorities for permission to use questions from such papers.

Particular care has been taken in the selection and preparation of illustrations for the book, and grateful acknowledgment is gladly made to the friends and industrial firms who have been good enough to provide photographs or other pictures for this purpose. The sources of most of such illustrations will be found indicated in the inscriptions to the figures themselves, but special thanks are due to the Macmillan Company, New York, and to the authors of three books published by that firm, who have been good enough to permit the use of illustrations from their books. The three volumes, to the authors of which I am much indebted for this privilege, are *Practical Chemistry*, by N. H. Black and Prof. J. B. Conant ; *Elements of Chemistry*, by Prof. H. N. Holmes and L. W. Mattern ; and *Practical Physics*, by N. H. Black and Prof. H. N. Davis. Mr. H. E. Hadley has also been good enough to permit me to use a number of illustrations from his excellent book, *Everyday Physics*, and a certain number of figures from other books published by Messrs. Macmillan and Co., Ltd., has been included. I am sure that interest in the text will be increased by the inclusion of so many figures illustrating principles or processes.

In conclusion, I wish to express my sincere thanks to Sir Richard Gregory, who suggested the preparation of this book to me and at every stage has generously given me most valuable advice and guidance. I am also greatly indebted to Mr. A. J. V. Gale, M.A., who together with Sir Richard Gregory has read through the proofs and offered many helpful criticisms.

L. M. PARSONS.

December, 1928.

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GRAVITATION AND ITS USES

THE progress of science depends mainly upon the patient labours of its numerous followers, but from time to time there arises some giant mind which gives the search for Truth a mighty push forward and leaves a colossal landmark along the road to Knowledge. Such was **Sir Isaac Newton,** the great mathematician, who was born in 1642 in the hamlet of Woolsthorpe, Lincolnshire. Originally it was intended that Newton should be, as his father, a farmer, but his interest in mathematics showed that he was destined for a different career, and he entered Trinity College, Cambridge, where he graduated in 1665. Four years later he was appointed Professor of Mathematics in that University.

Newton's earlier work consisted largely of researches on light or optics, and he was in the prime of life, about forty-five years of age, when his great work on gravitation was published. Whether the story of the falling apple is true or not, we owe to him the conception of the master force of the universe, the force that not only causes objects to fall to the earth, but keeps the planets and other heavenly bodies in their places. This great force called **gravitation** is one of attraction, and is capable of acting across apparently empty spaces, resembling magnetism in this respect.

Newton's Law of Universal Gravitation states that: *Every portion of matter attracts or tends to approach every other portion of matter in the universe with a force proportional to the masses and inversely as the square of the distance.* In order to understand this law we need some ideas concerning force and mass. **Force** is that which changes or tends to change a body's motion or disturbs its state of rest A force may exist though it does not become apparent unui objects move. The gravitational force exists before an apple falls from a tree, and only becomes apparent when something causes the tree to lose its hold on the apple. It is the force of gravity which prevents objects, including ourselves, from flying into space as the earth rapidly rotates on its axis.

The **mass** of a substance is the quantity of matter in it, and this quantity is usually represented by its weigh It must be understood, however, that should the force of gravity suddenly disappear, any object would contain the same quantity of matter as before; its mass would be unaltered. The pulling force existing between the earth and an object is measured by the weight of the object, and this force is mutual, each thing pulling the other.

According to Newton's Law, the gravitational force of attraction is less the farther apart bodies are from one another, and this diminution is not simply in proportion to the distance, but *according to the square of the distance.* Thus two bodies two feet apart attract each other with only one quarter of the force they would exert if placed one foot apart. An object falling to the ground becomes nearer and nearer to the centre of the earth as it descends. The distance is constantly lessening and the force is correspondingly increasing according to the law of inverse squares. The increasing force leads to increasing speed or velocity, so that an **acceleration** is obtained. This increase in velocity, which is not merely the rate of fall but the increase in that rate, is a definite extra distance of 32 *feet per second per second*, and this is termed the **acceleration due to gravity**. This quantity is of considerable importance in Physics and is denoted by the symbol **g**.

The significance of this acceleration can be appreciated when it is realised that bullets tossed into the air from an aeroplane

at a great height strike the earth with as great and deadly a velocity as if fired from a machine gun on the ground. The acceleration due to gravity is the same for all bodies, though air resistance influences the general rate of fall. Compare the descent of a parachute with that of a lump of stone. Dissimilar objects fall at the same rate in a vacuum where there is no air resistance.

CENTRE OF GRAVITY

There is a spot in every lump of matter, large or small, such that the whole weight of the lump appears to act from that point. This point is called the **centre of gravity.** In the case of a sphere of uniform composition, the centre of gravity coincides with the

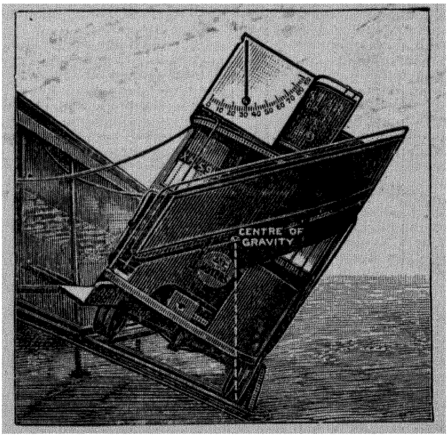


FIG. 117.

A RECENT TYPE OF MOTOR OMNIBUS CAN BE TILTED TO AN ANGLE OF 30° WITHOUT TOPPLING OVER PROVIDED THAT THE WEIGHT OF PASSENGERS IS EVENLY DISTRIBUTED.

geometrical centre of the sphere, and for this reason bodies fall vertically downwards towards the centre of the earth. But in masses of irregular shape, the centre of gravity is at some point determined by the shape of the body. Should the body be composed of various kinds of matter of different relative weights, for example, a lump of limestone containing fragments of lead ore,

then the centre of gravity would be determined not only by the shape but by the distribution of the constituents as well.

In daily life it is important that the centre of gravity of an object does not project beyond its 'base,' otherwise equilibrium is disturbed and the object falls over. Thus, a cart overturns when its centre of gravity projects beyond its wheel base or the area of the ground enclosed by the wheels (Fig. 117). Similarly a person will experience less tendency to fall, when swaying about, if his feet are placed wide apart because his 'base,' the area upon which he stands, is larger with his feet in this position. A flat piece of cardboard can be balanced on a pin point provided its centre of gravity rests on the pin. It is quite easy to find the centre of gravity of such a flat thin object. Two holes are pierced at different corners of the cardboard, and then thread is passed through one hole and the cardboard suspended. If a vertical line is drawn on the cardboard downwards from the point of suspension, the centre of gravity will be somewhere along this line. A weight on the end of a string, or a plumb-line, can be used to see that the line on the cardboard is drawn vertically. The cardboard should next be suspended from the other hole and another vertical line drawn as before. The point where the two lines intersect is the centre of gravity (Fig. 118).

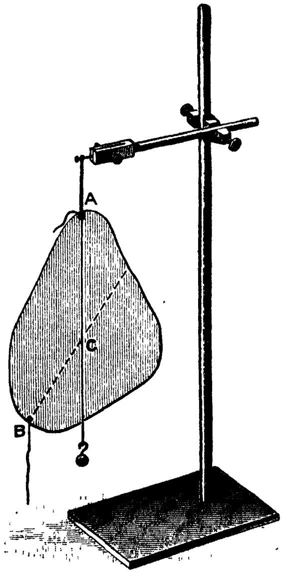


FIG. 118.
A METHOD OF FINDING THE CENTRE OF GRAVITY OF A PIECE OF CARDBOARD.

BALANCES

The principle of most weighing machines consists simply of balancing the weight of an article or commodity against that of standard units of weight. In scientific work where very accurate

results are necessary and where the amount of matter to be weighed is often very small, an exceedingly delicate balance must be employed. This kind of machine is described in the section dealing with chemistry. Any common balance such as that used in a grocer's shop is so well known that it is necessary here to indicate only the conditions of correct weighing. The beam must be properly balanced and consist of two exactly equal portions termed arms. The two scale pans must also be of equal weight, and the whole arrangement must be sufficiently sensitive for a small weight placed on either pan to disturb the equilibrium of the beam.

Accurate weighing can also be accomplished by means of a spring balance, an apparatus in which the pull of gravity is balanced against the tension of a spirally coiled wire (Fig. 119). An increase in stretch of the wire is proportional to an increase in weight of an object. Thus, a ten pound weight stretches the wire twice as much as does a five pound weight. There is an important difference between the principle of the spring balance and that of an ordinary balance. A pound of sugar would exactly balance a standard pound weight on an ordinary grocer's scales if the arrangement were taken to any place on the surface of the earth. Places are not all equidistant from the earth's centre, so that the force of gravity is not the same everywhere. But the gain or loss of gravitational pull on the pound of sugar would in all cases be equal to that on the standard weight. The tension of a spring balance works differently. At the equator the pound of sugar would stretch the spring a little less than it would do at one of the poles. The sugar would weigh more at the poles than at the equator. *A spring balance gives an accurate measurement of weight, and not merely mass.*

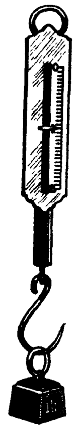


FIG. 119.
A SPRING BALANCE.

The use of gravitation as a source of power figures largely in daily life, clocks, lifts, and water wheels being operated by it.

CLOCKS

A grandfather clock is a mechanism worked by gravitation in two distinct ways. The fall of weights supplies the force necessary to keep the clock going, while the pendulum swings at a uniform rate so that correct time is kept. The useful properties of a pendulum depend upon certain facts which can easily be verified. If a weight is attached to a string, suitably suspended, and then given an initial push, it will be found that though the weight swings through a distance which becomes smaller and smaller, the time of any one swing is the same as that for any other swing. Count the number of complete swings (to *and* fro equals two swings) during the first 30 seconds, then the number of motions during the next 30 seconds, and so on. Now, if the string is lengthened, the pendulum swings more slowly, making a smaller number of oscillations per minute.

The length of a standard or seconds pendulum which completes a swing in exactly one second in London is 39·14 *inches.* This length is calculated from the point of suspension to a point within the ' bob ' called the centre of oscillation. The average domestic clock is smaller, hence its pendulum beats more rapidly and the clockwork, consisting of geared toothed wheels, must be so geared that correct time is kept.

Experiments prove that at a given place on the earth's surface, the time of swing of a simple pendulum varies directly as the square root of its length.

The intensity of gravity at a place is another factor of the period of swing, and recently much work of an academic nature has been done on the subject of the earth's shape. The vibration period of a standard pendulum of fixed length varies at different places, being longest over the equator and shortest over the poles. This means that the equatorial diameter is greater than the polar diameter of the earth. Hundreds of observations have been made and the mapped results show that the earth is a ball of very irregular shape, even more irregular than an oblate spheroid.

A pendulum exemplifies the fact that energy due to position may be converted to *kinetic* energy, or energy of motion. During

the first half or descending portion of a swing the bob is falling towards the earth, but during the second or ascending half of the motion its acquired kinetic energy carries it upwards against gravitation until the latter pulls it back again. If a heavier substance is used for the bob, does this make any difference to the period of swing? Experiments with equal volumes of iron, wood, and stone show that with a pendulum of fixed length the time of oscillation is not influenced by the weight of the bob. On account of friction with the air, any swinging pendulum gradually comes to rest unless some impulse is given to keep it going. The mainspring of a clock actuates a toothed wheel which engages with two other 'teeth' on a crossbar attached to the pendulum (Fig. 120). This arrangement, called an escapement, enables the spring to give a little kick to the pendulum at the right moment and so keeps it swinging; also by this means the pendulum controls the rotation of the toothed wheel.

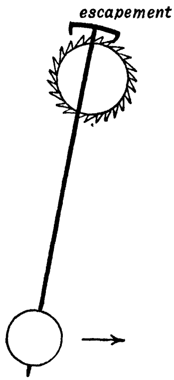


FIG. 120.—A SIMPLE PENDULUM AND ESCAPEMENT.

LIFTS

The fall of heavy weights is largely instrumental in the working of cliff railways, lifts, etc. In various mining operations use is made of large buckets or cages which run on wheels down a gently inclined overhead steel cable. Something is not obtained for nothing, so that a certain amount of other power must be used for hauling empty buckets up again. Cliff railways consist of two separate coaches, each standing on a wedge-shaped tank and connected together by a long steel cable passing over large grooved wheels at the top and bottom of the railway. The tank at the top is filled with water, making the carriage at the top of the incline heavier than that at the bottom; when it is released it therefore provides power to pull up the other empty tank and its coach. Again, a certain amount of power must be used to pump water to the required height unless lake or river water

is available at an altitude greater than that of the upper end of the railway. In the case of electrically-controlled lifts, used in large stores, flats, etc., heavy weights function as a counterpoise to balance the weight of the lift itself. Relatively small power is then required to raise the contents of the lift, and this, in an electric lift, is supplied by an electric motor situated either at the top or at the bottom of the deep well in which the lift operates. During descent the motor acts as a brake, preventing undue speed. A measure of safety is supplied by the fact that when the lift gates are not closed the electric circuit is incomplete and the motor will not work.

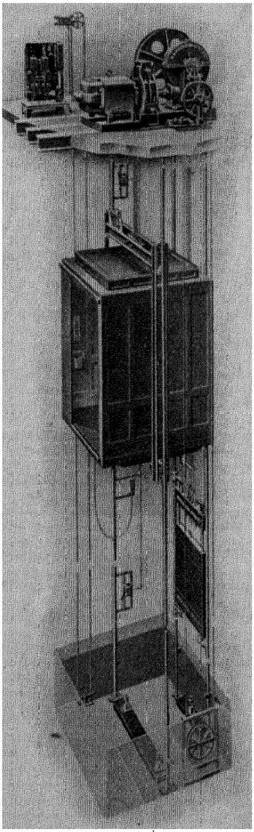


FIG. 121.—AN ELECTRIC LIFT AS EMPLOYED IN SERVICE FLATS, LARGE STORES, ETC.
(By courtesy of Messrs. Waygood-Otis.)

An interesting psychological effect of lift motion in relation to a person's weight may be observed. When a lift is moving either up or down at a uniform speed, a person experiences the sensation of being at rest while external objects rush past him; but as the lift slows down prior to stopping at the end of a descent, the retardation causes a sensation similar to that of being lifted. Psychologically, retardation downwards is equivalent to an acceleration upwards. Retardation at the top of an ascent causes a sensation of falling to be experienced. Upward retardation is mentally equivalent to acceleration downwards. These sensations are due to the reaction between the lift floor and the person.

WATER POWER

Until relatively recent times the form of apparatus for using the power of falling water was the simple water wheel, and the water was conducted to the wheel by means of open aqueducts or water courses. The wheel was of the overshot type if the water was conducted to the top of the wheel, and undershot if water was taken to the bottom of the wheel.

A greatly improved modern type of machine known as the **Pelton wheel** uses buckets instead of flat vanes and each bucket has a ridge across its middle (Fig. 122). Water from a considerable height is conducted through pipes to a nozzle which ejects it against the median ridge of each bucket in turn. The water is thrown out of any bucket in such a way as not to interfere with the next one. The power obtained depends upon the head of water, that is, the amount of fall, the quantity of water, and the size of the wheel. A Pelton wheel eight feet in diameter will develop 3000 horse-power when the head of water is about 800 feet.

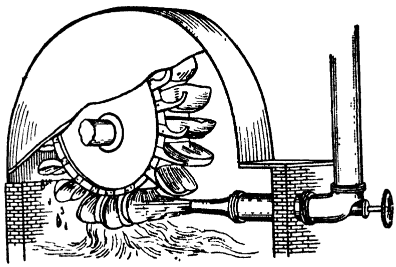


FIG. 122.—A PELTON WHEEL.

A still more recent development consists of the use of water **turbines** in which the water is forced against a series of curved blades connected to an axle, the whole being encased so that the water must pass through the machine. The interaction of the blades and water causes rapid rotation of the axle. Turbines can now be constructed to operate with a fall of water of only a few feet, and it is this type of turbine that must be used in connection with schemes to utilise the rise and fall of marine tides.

TIDES

The mutual attraction between the moon and the earth causes the water of the oceans to be heaped up, as it were, in line with

the moon. As the earth rotates on its axis it carries different places into the position where this bulge of water can occur, so that in turn they experience what is termed **high tide.** It appears to a person situated at one of these places that the tide, or in-

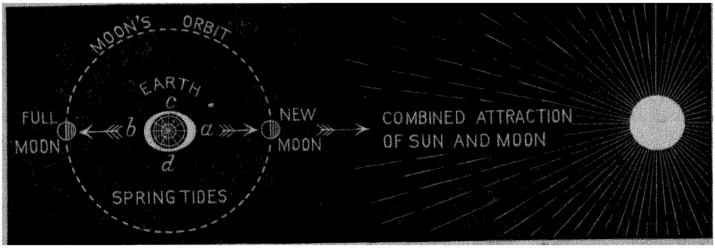


FIG. 123.—THE FORMATION OF SPRING TIDES
DUE TO THE COMBINED GRAVITATIONAL PULL OF THE MOON AND SUN.

creasing height of water, approaches him, but in reality he is moving towards the position where the high tide is produced. When a place has passed the position under the moon the tide falls, and is said to **ebb.** About 12 hours later the same place

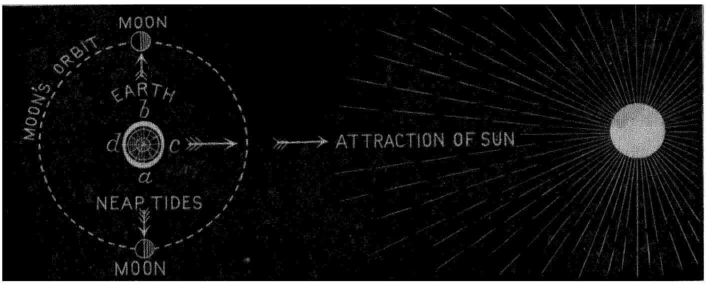


FIG. 124.—THE FORMATION OF NEAP TIDES
WHEN THE GRAVITATIONAL PULL OF THE MOON ACTS IN A DIRECTION AT RIGHT ANGLES TO THAT OF THE SUN.

experiences another high tide as it approaches another position where a water bulge is formed on the other side of the earth. If the moon did not move forward along its orbit there would be two high tides in 24 hours exactly, but owing to this movement of the moon, a place on the earth must rotate through

more than 360 degrees to come again under the moon. Hence there are two tides in 24 hours 50 minutes. When the sun and moon are in the same line, either on the same or on opposite sides of the earth, these two bodies act in conjunction and very high **spring tides** are the result (Fig. 123). Such occur at the time of new and full moon. If the sun and moon are at right angles or in opposition, the forces are opposed, but the moon, though its mass is so much smaller, gets the better of it on account of its proximity to the earth. At these times lower **neap tides** occur under the moon, which then appears as a semicircular disc and is in the position of either first or third quarter (Fig. 124).

Power may be obtained from the daily rise and fall of the tide, but, so far, schemes for this purpose have met with very limited success. Although huge volumes of water may be lifted into reservoirs by each tide, such water is lifted only once in twelve hours, and the *average* uplift is only some ten or twelve feet. The certain periodic rise of the tide, irrespective of weather, is heavily counterbalanced by its slowness, and whether any adequate means of dealing with the matter can be found is a problem for the future to solve.

Many technical problems, alike in mechanical, electrical and hydraulic engineering, still require to be coordinated and solved before a tidal scheme of any large magnitude can be embarked upon with confidence. ‘On the other hand,’ remarked a writer on the subject in *Nature* of June 3, 1920, ‘the possibilities of tidal power, if it can be developed commercially, are very great. Assuming a mean tidal range of only 20 feet at springs, and 10 feet at neaps, and adopting the single-basin method of development with operation on both rising and falling tides, each square mile of basin area would be capable, without storage, of giving an average daily output of approximately 110,000 horse-power-hours. In such an estuary as the Severn, where an area of 20 square miles could readily be utilised with a spring tidal range of 42 feet, the average daily output, without storage, would be approximately 10,000,000 horse-power-hours.’

CHAPTER XIV

MOTION, ENERGY, AND WORK

MOTION may be regarded as that which produces a change in the position of an object relative to the positions of other objects. The motion of a train changes its position relative to the station it has just left, and to the objects it passes as it proceeds upon its way. So many objects encountered in our daily round of activities are so frequently changing their positions relative to one another that the process of living is one in which motion plays a very important part.

Many objects which appear to be stationary or at rest in relation to other things near them are found to be in motion, or changing their positions, when considered in relation to something else. Thus a house appears stationary when its position relative to the ground upon which it stands, other houses, roads, and people passing in and out, is considered; but it, with the ground on which it stands, is changing its position relative to that of the sun and stars.

Similarly, a person sitting in a motor car is at rest so far as the motor car is concerned, but in motion relative to the road and surrounding objects. *Motion and rest are relative, not absolute.*

Let us admit the truth of this statement and proceed to consider certain facts relating to motion and rest as they affect our daily affairs. The garden roller is at rest in the tool shed, and if I wish to roll the lawn I must exert a force to set the roller in motion. The roller is inert until the applied force overcomes its **inertia** and causes it to move.

If in the process of rolling the lawn something occurs which necessitates the roller being stopped quickly, a force has to be exerted to stop its motion. *Its tendency to keep on moving once*

it has been started is also due to inertia. Hence inertia may be defined simply as the tendency of a body to remain as it is either at rest or in steady motion (Fig. 125). The planets have been revolving around the sun during many millions of years because of their inertia ; it would require an inconceivably great force to stop their motions. The earth continues to rotate on its own axis for the same reason. But on the surface of the earth the objects we have to deal with do not move for ever once they are set in motion. Many attempts to produce a machine capable of perpetual motion have been made but none has succeeded. The enemy of motion is **friction,** due to the rubbing of one object against another. Even a gas, such as the air, is capable of producing friction with objects rushing through it. Meteoric fragments proceeding at great speed through the upper air become white hot as the result of friction. Beyond the upper limits of the atmosphere in vast spaces devoid of ordinary matter the planets keep 'the even tenour of their way' because of their own inertia and the absence of friction.

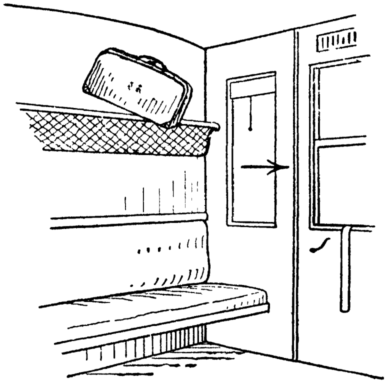


FIG. 125.—AN EXAMPLE OF INERTIA

AS THE TRAIN, WHICH IS TRAVELLING IN THE DIRECTION OF THE ARROW, SUDDENLY SLOWS DOWN A HANDBAG MAY BE THROWN FORWARD BY ITS TENDENCY TO KEEP IN MOTION.

A considerable force is required to start the motion of a roller, that is, to give it an **acceleration,** but once started no force would be necessary for continued motion if it were not for friction. As it is, sufficient force must be applied to overcome this friction. The amount of friction in any case depends largely upon the nature of the surfaces in contact, upon the shape of such surfaces, and upon the weight of the objects. In general, the smoother things are the less the friction. Very little force is required to produce motion in the case of a man skating upon ice, but con-

siderable force is necessary to drag a heavy box along the ground.

In a great many ways friction is a hindrance and means have to be employed to lessen it. Lubricants, such as grease and oil, are applied to moving parts of machinery, but in many applications the method of reducing friction consists in the use of either spherical or circular surfaces. Ball bearings afford an example of the former (Fig. 126) and a wheel is an example of the latter. Such devices lessen the number of points of contact and result in friction due to rolling and not to sliding. *Rolling friction is less than sliding friction*, other things being equal, and in hard steel wheels on steel railway lines we have an example of friction

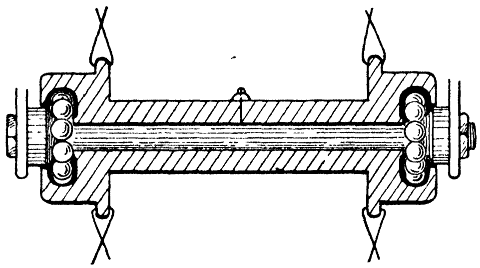


FIG. 126.—SECTION OF THE AXLE OF A BICYCLE WHEEL.
SHOWING BALL BEARINGS TO REDUCE FRICTION.

reduced to a practical minimum. Though friction is often an obstacle, it must not be overlooked that without friction life as we know it would be impossible. The actual friction between the wheels and the rails is necessary to start a train's motion. Similarly with walking, friction between our feet and the ground is a necessary condition of forward motion, and friction is required to stop trains, motor cars, and other objects in motion. It is also the principle on which the action of the clutch of a motor car depends (Fig. 127).

Inertia plays a very important part in many ways. Though it is a hindrance when we wish to start a machine or move an object, it is a great advantage once a machine has been started. For example, the moving flywheel of an engine possesses considerable inertia in virtue of which energy is stored up, and the

engine keeps working steadily although the power is actually applied intermittently. As in the case of friction, the greater the weight the greater the inertia, hence a heavy flywheel takes much more force to start it, but will also require much force to stop it.

Other aspects of motion must now be considered. At the commencement of its motion a train moves slowly, the pull of the engine being used to overcome friction and inertia, but very soon it moves more quickly, and its motion is said to be accelerated. The acceleration is measured by the number of feet per

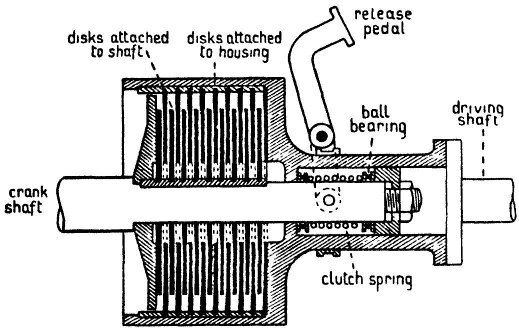


FIG. 127.—THE CLUTCH OF A MOTOR CAR.

FRICTION BETWEEN THE TWO SETS OF DISCS COMMUNICATES THE MOVEMENTS OF THE ENGINE TO THE SHAFT OF THE CAR. THE DRIVING SHAFT CAN BE FREED FROM THE ENGINE CRANK SHAFT, AS IN CHANGING GEAR, BY SEPARATING THE DISKS BY THE 'RELEASE PEDAL.'

second by which the velocity is increased. In the previous chapter it was shown that under the influence of gravity a falling object has an acceleration of 32 feet per second per second, but a train's speed accelerates at a much slower rate, about $\frac{1}{5}$ foot per second per second. The rate of motion of a train or other moving object irrespective of the direction of motion is known as **speed,** and the term **velocity** applies not only to the rate of motion but also to the direction as well.

A moving body acquires **momentum,** and the amount of momentum depends upon the amount of matter or mass of the object and its velocity. Thus **momentum = mass × velocity.** If two bodies travelling in opposite directions collide, the one having the smaller momentum will be pushed backwards by the other one. A large flywheel on an engine has more momentum than

a small one composed of the same material though both are moving at the same speed.

If two flywheels of exactly equal mass are moving at different speeds the momentum will be greater in the one having the greater speed. Practical applications of momentum are numerous, a pile-driver, which is essentially a large heavy weight employed for driving wooden poles into the ground and an ordinary hammer being other examples.

FORCE, ENERGY, AND WORK

It is by no means easy to define the exact nature of **force,** but anyone can realise what is meant by the statement that it requires force to move a garden roller. A force must be applied to an object if we wish to do any one or more of the following:

(1) Disturb the object from a state of rest or steady motion. (2) Increase its rate of motion. (3) Overcome friction and keep it moving at the same rate. (4) Alter the direction of its movement. (5) Stop its motion once it has been set going.

A railway train may illustrate any of these applications of force. The first three are obvious, and an example of No. 4 occurs as a train is rounding a curve, the force between the rails and wheels causing an alteration in direction. The application of the brakes to stop the train illustrates No. 5.

Another example of a force changing the direction of motion is afforded by gravitation, which has caused the planets to revolve around the sun in elliptical orbits instead of proceeding along straight lines.

Common personal experience shows that more force is required to give the same acceleration to a larger mass than to a smaller mass. Also it is clear that with an object of given mass it requires more force to move it quickly than to move it slowly. Combining these factors we have,

Force = mass × acceleration, a law formulated by Newton.

When two forces act in different directions upon a body, that body will move in a direction and with an acceleration resulting from the combination of the two forces; hence we speak of the resultant force and acceleration. Simple problems on such

combinations of forces can be solved graphically by the **parallelogram of forces.** The resultant force urging a ship forward when pulled by two tugs A and B is of such magnitude and direction that it is represented by the diagonal OR of the parallelogram OBRA (Fig. 128). Of course it is important that the lengths and directions of the lines OA and OB represent correctly the amount and direction of the force exerted by tugs A and B respectively.

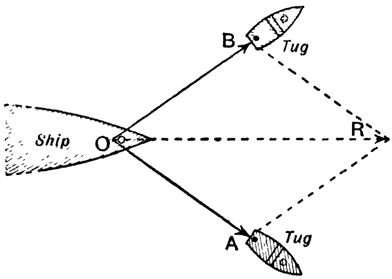


FIG. 128.
THE SHIP WILL MOVE IN THE DIRECTION *OR* AS THE RESULT OF THE FORCES EXERTED BY THE TUGS *A* AND *B*.

A force causes an object to move, and in virtue of that motion the object possesses **energy**, and such energy due to motion is said to be **kinetic**. A weight, such as that used in a grandfather clock, possesses energy because of its position, and this is known as **potential** energy.

In either case, kinetic or potential, *energy is the capacity to do work.* The kinetic energy of the piston in the cylinder of a gas engine does work in operating various machines in a factory, and the potential energy of the falling water at Niagara does work in operating the dynamos which generate electricity (Fig. 129).

Anything capable of doing work is regarded as a form of energy, and when necessary one form of energy can be converted to another form before certain useful work is performed. Let us trace the various transformations of energy and the kinds of work performed in the case of an ordinary steam engine connected to a dynamo for the generation of electricity. The coal in the fire box burns because it has a chemical attraction for oxygen of the air, and this chemical attraction has energy which develops heat, another form of energy. This heat does work in changing water to steam, which then expands and exerts a pressure, so causing the piston to move and acquire kinetic energy that does work in forcing a wheel to rotate. The wheel being connected to, or *coupled* with, the armature of a dynamo, the latter also moves and electricity is generated. Such elec-

tricity can then be taken along wires and made to do useful work such as operate tramcars, light lamps in houses, cook meals, electroplate various objects, etc. Since chemical attraction, heat, and electricity are capable of doing work, they also are forms of energy.

So is gravitation, and in engineering practice the capacity of an engine for doing work is expressed in terms of the weight it

FIG. 129.—AERIAL VIEW OF NIAGARA FALLS,
WHERE IN FOUR DEVELOPMENTS ON THE ONTARIO SIDE ALMOST HALF-A-MILLION HORSE-POWER IS INSTALLED.
(By permission of the Director, Department of the Interior, Canada.)

can lift against the force of gravity. The fundamental unit employed is the **foot-pound,** or the amount of work done in lifting a one pound weight through a vertical distance of one foot. **James Watt,** the inventor of the steam engine, found that a horse could raise a weight of 150 lb. through 220 feet in one minute. Hence the *practical unit* of **one horse-power = 33,000 foot-pounds per minute.**

The *average* amount of manual work done by an active man is equal to $\frac{1}{8}$ horse-power; the engines of motor cars vary in horse-power from 7 to 30; gas engines, employed in factories to operate machinery, range from $\frac{1}{2}$ to 260 horse-power, while the maximum horse-power of a large first class battle crusier is about 120,000. The unit 'horse-power' is generally written as H.P.

It is quite easy to calculate the amount of power required to perform a simple type of work. Thus, suppose we have to find the power which must be exerted to lift a hundredweight of coal from the road to a flat 30 feet above ground level. The foot-pounds necessary are $112 \times 30 = 3360$, and this is a little more than $\frac{1}{10}$ of a horse-power if the act of carrying the coal up this distance takes exactly one minute. Should the work require only 30 seconds, the same energy has been used in half the time, and the power exerted is just over $\frac{1}{5}$ H.P. This is the power required to *raise the coal only*; in reality the man also lifts his own body through the same distance, and this requires more power. During a short period a man can expend energy at a much greater rate than $\frac{1}{8}$ H.P.

When one form of energy is converted to another for our convenience, a certain amount of energy is wasted though not destroyed. Thus falling water can be used to drive turbines and so generate electricity, but we do not obtain all the foot-pounds in the form of electricity. A considerable percentage of the original energy is converted to heat on account of friction between the parts of the machinery and this heat is of no practical use. If 70 per cent. of the original energy is obtained in the form of electricity, we say that the machinery has an efficiency of 70 per cent. The wasted 30 per cent. of the energy is not destroyed but is simply not harnessed for practical purposes. *Though energy is often wasted it cannot be destroyed, neither can it be created*, the sum total of energy remains unchanged, a fact briefly described as the **conservation of energy.**

MECHANICAL ADVANTAGE AND SIMPLE MECHANISMS

Since energy cannot be created, how is it that the small force exerted by a man can raise a very heavy weight quite easily when

he uses a simple arrangement called a **lever,** consisting of a long rod and a pivoting point or **fulcrum** about which the rod turns? If the man is to raise the heavy weight, the distance from the fulcrum to the weight must be much less than that from the fulcrum to the man's hand. When this is the case, the man's arm moves downwards through a big distance as the heavy weight moves upwards through a small distance. A small force moving through a larger distance equals a larger force moving through a smaller distance in the same time. The lever has given the man a **mechanical advantage** in permitting him to make use of distance,

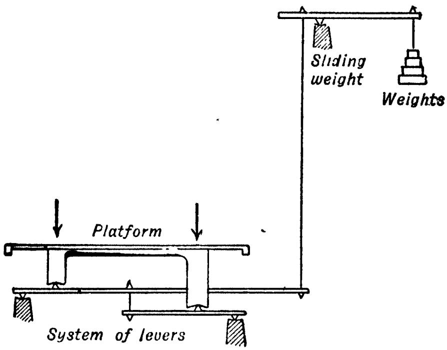


FIG. 130.—DIAGRAM OF A PLATFORM WEIGHING MACHINE USED AT RAILWAY STATIONS.

and the greater the ratio of the distance through which the man's hand moves to that through which the weight moves (called the **velocity ratio**) the greater the mechanical advantage obtained. Their distances depend upon the position of the fulcrum. Suppose the fulcrum to be placed one foot from the heavy object and six feet from the man's hand, then theoretically the mechanical advantage should be six, and a weight of three hundredweight should be lifted by a continued hand pressure equal to 56 lb. Actually the mechanical advantage is a little less than 6 owing to loss of efficiency through friction. Since the man's hand moves through six times the distance the weight moves through in the same time, the velocity of the hand is six times that of the weight; the velocity ratio is six.

A simple lever may be used to balance unequal weights placed

at different distances from the fulcrum, the lesser weight being at a greater distance than the heavier one. On a seesaw a small child weighing four stone placed nine feet from the fulcrum balances a twelve stone man situated only three feet from the fulcrum, and as they move up and down the child will move through three times the vertical distance the man moves through.

A chemical balance and an ordinary grocer's scales are arrangements in which there is no real mechanical advantage

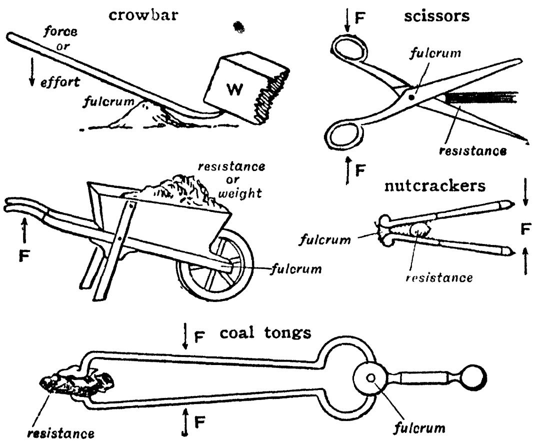


FIG. 131.—EXAMPLES OF COMMON OBJECTS WHICH FUNCTION AS LEVERS.

since the weights on both sides are equal, but in the machine for weighing luggage at a railway station considerable advantage is gained by a system of levers so that quite a small weight balances a large one (Fig. 130). The weighbridge in the road outside a station, and used for weighing trucks of coal, etc., also consists of a platform resting on a system of levers, so that a big mechanical advantage is obtained and relatively small weights balance the load.

Three classes of levers are recognised according to the relative positions of the force, the fulcrum, and the load or weight. If the fulcrum is situated between the force (F) and the weight (W), the lever is of the first class, an example being a crowbar, while a pair of scissors is a double lever of this class. (Fig. 131.)

In levers of the second class the weight comes between the force and the fulcrum, as in a wheelbarrow and in a crowbar, using the ground as a fulcrum. A pair of nutcrackers is a double lever of this class. When the force is applied between the fulcrum and the weight the lever is said to be of the third class, a pair of coal tongs being a double lever of this type.

A little consideration will enable a student to classify the following for himself: pump handle, tin-opener, pair of bellows, address stamper, a bird's wing, a door hinge.

Other means of obtaining mechanical advantage are afforded by **screws, wheels,** and **pulleys.** In an ordinary winch used for drawing water from a well, the handle moves on a much larger circle than that of a point on the cylindrical drum upon which the rope winds or unwinds itself. Consequently a smaller force on the handle can balance a larger force due to the weight of water being lifted, and the mechanical advantage is determined by the relative radii of the two circles, that described by a point on the cylinder and that described by the hand.

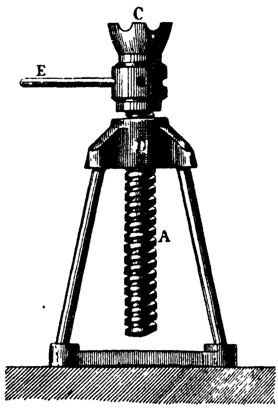


FIG. 132.—A SCREW JACK

The principle of an ordinary screw is somewhat similar. The lower part of a screw possesses a spiral groove called a *thread*, and the vertical distance between two consecutive turns of the thread is called the step. One rotation of the screw forces it into a piece of wood a distance equal to the step, and the mechanical advantage obtained equals

$$\frac{\text{circumference of circle described by the hand}}{\text{step of screw}}$$

from which it follows that a screwdriver having a wide handle gives a bigger mechanical advantage than one with a small handle.

An office letter-copying press is a good practical application of the principle of the screw.

An ordinary **jack** for lifting the wheel of a motor vehicle

consists of a smaller toothed wheel meshing with a larger wheel connected to a vertical screw ; many turns of the smaller wheel result in fewer turns of the larger wheel and slower turning of the screw, hence the mechanical advantage is very great and very heavy loads may be lifted. A simple type of screw-jack is illustrated by Fig. 132.

In building and engineering operations heavy masses of stone, steel, etc., are raised into place by means of an arrangement of wheels and chains (or ropes) called a **pulley.** For very

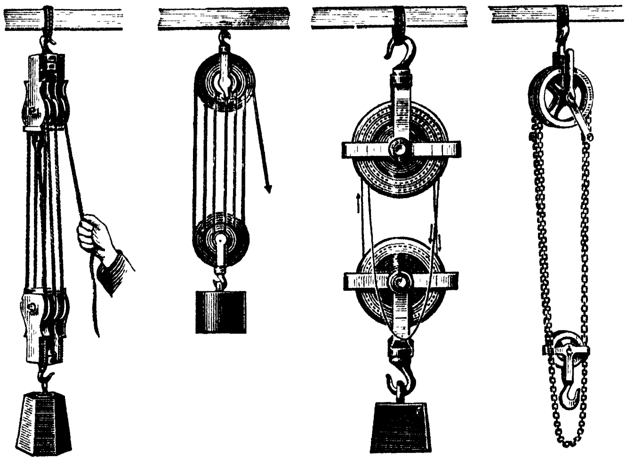


FIG. 133.—VARIOUS TYPES OF PULLEY.

heavy materials the pulleys are attached to cranes and worked by engines.

The simplest kind of pulley consists of a rope passed over a grooved wheel suspended from a strong overhead beam or support. If a weight is attached to one end of the rope, the weight can be raised, but there is no mechanical advantage. If a weight of 56 lb. is raised one foot, the man exerts a continued pull of 56 lb. through one foot. Since it is easier to pull downwards than upwards, a certain physiological or muscular advantage is gained and that is all. But if the number of grooved wheels is increased a mechanical advantage can be obtained.

By causing the rope to pass over several wheels, as in a builder's single rope pulley, distance is again employed, and a smaller weight (or pressure) moving through a larger distance can raise a heavier weight through a small distance. The mechanical advantage obtained depends upon the number of wheels employed; if this be four, then theoretically the mechanical advantage is 4, and so on, with this class of pulley, but it must be remembered that friction and the weight of fittings always mean a certain loss of efficiency. Another type of small but powerful pulley used by builders employs an endless chain.

Another means of reducing the force required by increasing the distance is that known as an **inclined plane.** If a body is to be moved to a position higher than its present level, say a distance of 100 feet, it can be moved vertically, or it may be caused to move along an inclined surface the length of which is greater than the vertical distance of 100 feet. It will require less force per second to move the object up the inclined plane than that required to move it vertically. The mechanical advantage of such a plane is determined by the ratio of its length to the height. The practical application of this principle is more common than any form of lever or pulley, since any gradient on any roadway or railway line is an example of it. A person ascending a ladder or a staircase, and trucks ascending slopes in mines are other examples.

CHAPTER XV

MATTER AND SOME OF ITS PROPERTIES

THE various objects which form the external world around us, also our own bodies, are composed of some sort of substance or **matter.** We appreciate the reality of these objects because we perceive them through our senses—touch, sight, hearing, smell, and taste. Of course any one object does not usually affect all of our senses, but we see and feel most things. Substances which are invisible may be felt or smelt, as in the case of a stream of coal gas issuing from a jet; others may be felt only, for example, a moving mass of air commonly called a wind. Sometimes substances, such as diffused coal gas or poisonous sewer gas, may be perceived only through the sense of smell. Taste is generally associated with sight and touch when we eat our food. In all these cases we become aware of the existence of matter because it produces sense impressions in our minds. Hence matter may be defined as *the external reality equivalent to certain sense impressions experienced by us.*

Very little consideration is necessary for us to realise that there are **three physical states** assumed by matter—**solid, liquid,** and **gas**—extremely common examples of each being stone, water, and air respectively. It must be observed that the solid, liquid, and gaseous states are *physical* conditions, and the same substance may exist in any one of these forms. Thus ice, water, and steam are all the same thing so far as the sort of matter is concerned, but the physical states are different. Many other varieties of matter met with in daily life may exist in any of the three physical states, the chief controlling condition being temperature, though pressure is another factor which must not be overlooked. With ordinary conditions of temperature and

pressure any substance exists in one state, solid, *or* liquid, *or* gas. Air is normally gaseous, but if the temperature is lowered sufficiently it becomes liquid, and if a still lower temperature is produced it becomes solid. The great majority of common substances are solid at ordinary temperatures, but by heating them sufficiently many of them may be converted to the liquid and gaseous states. Thus ice, sulphur, and wax are easily liquefied and vaporised, but on the other hand such materials as rock and carbon remain solid even at high temperatures, though at sufficiently high temperatures even rock is liquefied, as in volcanic eruptions, and carbon becomes gaseous (Chapter XLII).

Metals become liquid at fairly high temperatures, though pure tin melts at the relatively low temperature of 232° C. Water, oils, and mineral acids are examples of materials normally in the liquid state.

Though most substances in changing their physical state pass from solid to liquid, and then from liquid to gas, there are a few materials which proceed straight from the solid to the gaseous state, or on cooling pass straight from vapour to solid. The nearly black glistening substance called iodine is an example. In certain granite areas crystals of copper and tin ore are found as mineral veins traversing cracks in the surrounding rocks. Similarly lead ore and barytes, a mineral used for the manufacture of paint and other purposes, occur as veins in limestone regions. All these substances are insoluble in water, and so cannot have been deposited from water solutions, as rock salt and some other minerals have been. It is believed that heated vapours containing compounds of tin, copper, lead, and barium were, on cooling, changed directly from vapour to solid without an intervening liquid state.

MOLECULES AND THE DISCONTINUITY OF MATTER

If your foot collides violently with a large lump of granite you become painfully aware of the fact that the granite is impenetrable so far as your foot is concerned. But is it impenetrable as regards every other kind of matter? Experiments upon

rocks of various kinds, including granite, show that they contain numerous minute spaces or pores capable of containing water or other substances possessing the power of penetrating into them.

There are many reasons for believing that even substances such as iron and steel are not so compact as they appear to be. The behaviour of matter causes us to assume that any body is composed of a vast number of minute units called **molecules** and that these molecules are not in contact with one another but are separated by intermolecular spaces. *Matter in all its forms is discontinuous.* The molecules are so small that they cannot be seen even with a high power microscope, but we realise that they are there all the same. The study of heat compels us to believe that the molecules are not only separated by spaces but also are in constant motion, a fact which explains why a gas always fills a space. The relative distances between adjacent molecules, or in other words the freedom for motion of the molecules, is related to the physical state of a substance. In solids the molecules are nearer together than they are in either liquids or gases, and in gases they are very much more widely separated than they are in liquids.

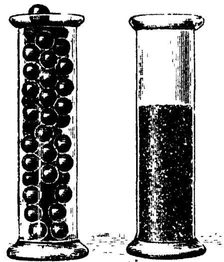


FIG. 134.—AN ILLUSTRATION REPRESENTING INTERMOLECULAR SPACES.

THE SAND IN THE SECOND VESSEL CAN BE MADE TO OCCUPY THE SPACES BETWEEN THE MARBLES IN THE FIRST VESSEL.

Several important properties of matter are the direct result of this variation in the dimensions of the intermolecular spaces. In solids the molecules are not so free to move about, hence solids are more or less *rigid* and are capable of retaining any sort of shape in normal circumstances. A cube of sugar remains a cube—its molecules do not flow in various directions; even a piece of clay retains its shape unless special force is exerted to alter its form. These facts can be stated differently by saying that *a solid is capable of retaining any number of free faces*, that is, faces or surfaces unaffected by the walls of a containing vessel. A cube of sugar placed in a cup is still a cube; its faces or surfaces retain their individuality as it were. Now

in a liquid the molecules are more widely spaced and are much more capable of motion, hence *the liquid is not rigid*, and when placed in a vessel *it has only one free face, its upper surface, and this is always horizontal.* With the exception of this one free face its shape is moulded by the containing vessel. The molecules of a gas are still more widely spaced and more free to move, so that *a gas always fills a containing vessel whether the pressure upon it is great or small, and there are no free faces at all.* Some idea of the relative freedom of molecules in a gas may be obtained from the fact that a cubic foot of water on being boiled gives 1600 cubic feet of steam at the usual atmospheric pressure.

Both liquids and gases are termed **fluids** because they are not rigid—their molecules are free to flow easily from one position to another—but it must be noted that different liquids exhibit different degrees of **mobility** ; in some, such as water, the particles are more mobile than those of others, for example treacle, which exhibits a greater degree of **viscosity.**

It can be shown quite easily that liquids such as water contain spaces between the molecules. If some water is placed in a measuring glass, its surface level noted, and then some common salt is placed in it, the salt disappears or **dissolves** without raising the level of the water. The salt in dissolving distributes itself regularly among the spaces between the water molecules, so forming a **solution,** and the water is described as a **solvent.** The solvent property of water is of great practical importance, as pointed out in later chapters; but as examples of such useful aqueous solutions, we may here refer to various medicines, thermal and medicinal springs, chemical and photographic reagents, electrolytes for electroplating, certain solutions used in chemical industries, dyeing, brewing, etc. A few water solutions are a nuisance, one of the more common examples being that of bicarbonate of lime obtained from limestone districts. This substance (and others) renders the water hard, so that it must be softened by various means (see Chapter XXXIV) before it can be used in steam boilers and laundries.

These properties of water are due to the fact that it is porous ; in reality it is much more porous than many solids of the same dimensions. There are other solvents besides water. Thus

the liquid called acetone dissolves the gas acetylene used for house lighting; substances such as resin and wax dissolve in alcohol, and many solids insoluble in water dissolve in dilute acids, though in this case a chemical change takes place before solution is accomplished. Some liquids can dissolve in other liquids; for example, oils dissolve in alcohol, and as in the case of

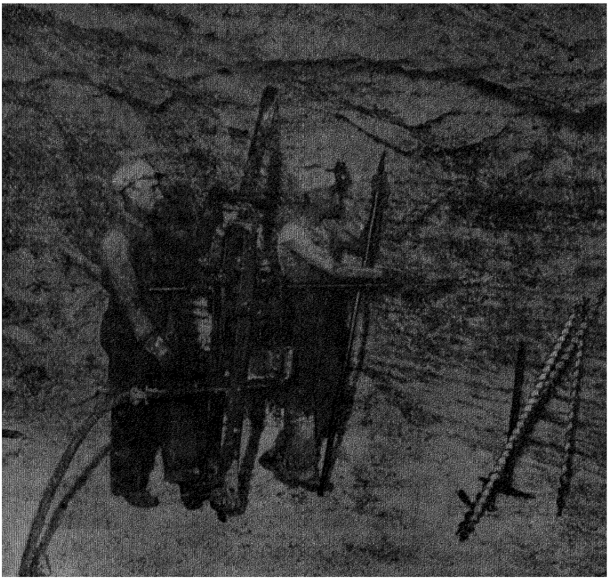


FIG. 135.—MINING SALT.
THE SALT IS DUE TO FORMER SOLUTION AND EVAPORATION.

dissolved solids, such a solution results from the intermolecular spaces of one liquid being occupied by the molecules of the other.

If clear water is carefully placed in contact and above another liquid, say a purple solution of potassium permanganate, for a short time, the heavier, coloured liquid remains below and they appear separate, but very soon they commence to interpenetrate and finally form a mixture of uniform colour. The molecules of each have occupied the interspaces of the other by a process known as **diffusion.**

Gases also diffuse in this way; any gas in attempting to fill a given space occupies the interspaces of another, and such a mixture may be of an explosive character, as when air is mixed with from 5 per cent. to 14 per cent. of coal gas. If gases did not diffuse, they would arrange themselves with a lighter one above and a heavier one below, and explosive mixtures would not be so easily formed. Diffusion of gases proceeds at different rates, and it has been found that the lighter the gas, the more quickly it occupies the spaces between the molecules of another gas. Diffusion explains why a heavier gas, such as carbon dioxide in a vessel surrounded by lighter air, will partly leave the vessel and ascend into the air, while some air descends into the vessel and mixes with the remaining carbon dioxide. The spread of such gases among the particles of air is a cause for the necessity of good ventilation in rooms and mines.

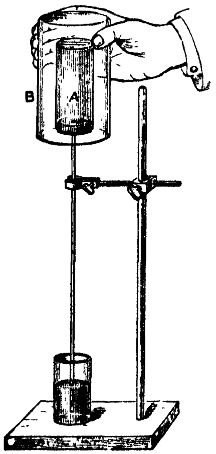


FIG. 136.—AN EXAMPLE OF DIFFUSION OF GASES.

HYDROGEN IN THE POROUS VESSEL *A* DIFFUSES INTO THE AIR IN *B* WITH THE RESULT THAT WATER RISES IN THE TUBE.

When two liquids or two gases are separated by a solid porous partition such as parchment or unglazed earthenware, diffusion through the partition takes place and the process is then known as **osmosis.** Practical consequences of osmosis are of some importance; for example, water passes through the cell walls of the root hairs of plants as explained in Chapter V., and in some forms of electric battery an earthenware porous partition is employed to separate certain substances, at the same time permitting hydrogen gas to pass through. Substances dissolved in water may be divided into two classes—**crystalloids,** like common salt, which easily diffuse through a porous partition, and **colloids,** such as white of egg and glue, which do not pass at all, or do so with difficulty.

CAPILLARITY AND SURFACE TENSION

The particles forming a piece of wood are held together by a force of attraction ; they are said to **cohere.** The particles of a liquid do not cohere so well as do those of a solid, and in a gas the cohesion is not apparent at all. When a piece of glass or one's finger is dipped in water, on withdrawing the finger some water **adheres** to it, hence the term adhesion refers to the attachment of particles of one kind of matter to an object composed of another kind. Certain facts relating to cohesion and adhesion are of interest. If you place your finger in mercury instead of water, particles do not adhere to your finger, because in mercury cohesion is stronger than adhesion. In water the reverse is true; hence most objects dipped in it and then withdrawn are made wet.

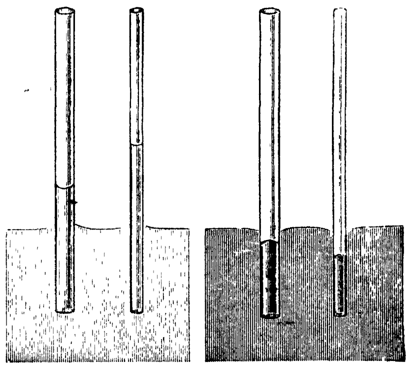


FIG. 137.—CAPILLARY TUBES.
WATER STANDS ABOVE, MERCURY BELOW, THE OUTER WATER SURFACE.

If a glass rod is placed in water, the surface of the water against the rod is curved upwards instead of remaining horizontal because the force of adhesion is greater than that of cohesion. When a piece of glass tubing is employed instead of a rod, water also rises inside the tube, and if the latter is very narrow the water will rise a considerable distance. (Fig. 137.) The water in the tube is first curved upwards, then tends to straighten itself horizontally again, then curves upwards a little farther, and so on, until the weight of the little water column exerts a pressure sufficient to stop further horizontal straightening. This process of a liquid creeping upwards in a narrow tube is termed **capillarity,** and the narrow tube is called a **capillary** tube. Oil ascends the wick of a lamp, or melted wax rises in the wick of a candle by this process. Specimens of a patient's blood are sent in sealed capillary tubes to bacteriologists for examination to see

if certain disease germs are present. Capillarity is also responsible for the upward motion of water in muslin or similar fabrics, and is one of the factors producing the movement of water upwards through the stems of plants.

Liquids, particularly water, behave as if a fine skin covered the surface, such a skin effect resulting in the spherical shape assumed by *small* drops of water as in rain and dew. The sphere has the smallest surface area for a given volume of liquid and is, when possible, the shape assumed when a surface behaves as if it were composed of stretched rubber. **Surface tension,** in causing the water to assume the least surface possible, is thus responsible for the spherical form of small drops. In larger volumes the surface tension is too weak to balance the weight, which causes the water or other liquid to assume the form of flattened globules. The tendency of surface tension to form rounded drops is well illustrated by water slowly dripping from a tap. (Fig. 138.)

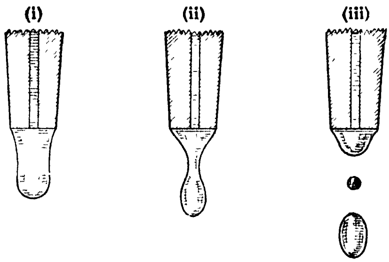


FIG. 138.—SURFACE TENSION OF WATER.
STAGES IN THE FORMATION OF A DROP.

ELASTICITY

If a glass or steel ball is dropped upon a hard stone floor it rebounds nearly as high as the position from which it was dropped, but a piece of stone scarcely rebounds at all. Why is this? When the glass marble strikes the floor it is slightly flattened at the point of contact. (Fig. 139.) But it strongly resists this flattening and immediately regains its former shape with the result that it kicks off from the ground. The stone exhibits only a feeble tendency to recover its shape, so it does not push off with anything like the same force. The tendency to recover original shape is called **elasticity,** and glass is much more elastic than stone. Indiarubber or 'elastic' makes elasticity apparent, but it is not nearly so elastic as glass or steel.

Certain disturbances known as wave-motion (see Chapter XXII) proceed more quickly in substances having a marked degree of elasticity. Thus sound waves pass much more quickly through steel than through wood, and a tuning-fork used in music is made of steel because its rapid oscillations result from the high degree of elasticity. At times earthquake waves pass through the centre of the world right from one side to the other in about twenty minutes because the substances forming the inside of the earth are more rigid than steel and possess a greater degree of elasticity.

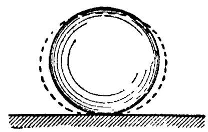


FIG. 139.—ELASTICITY OF A GLASS BALL.

ON STRIKING THE GROUND THE BALL IS DISTORTED, BUT IT IMMEDIATELY RECOVERS ITS SHAPE AND REBOUNDS.

Both liquids and gases exhibit **elasticity of volume**; that is, they show a marked tendency to recover their original volume when a compressing force is removed. In this sense a gas, so long as it is not near the temperature at which it liquefies, is perfectly elastic, the volume always recovering its original dimensions exactly when the pressure again becomes exactly as it was before. Liquids behave in a very similar manner, but there is this important difference: whereas gases can be compressed to a very minute fraction of their original volume if the pressure is sufficiently great, liquids are only slightly compressible. No matter how great the pressure exerted upon water, its volume is decreased by an extremely small amount.

The Pacific Ocean is in places more than five miles deep, so that the pressure near the ocean floor must be enormous. In spite of this, however, the density of deep oceanic water is only very little more than that of the surface water. The very slight compressibility of water plays an important part in the transmission of pressure in such appliances as hydraulic presses and lifts described in the next chapter.

CHAPTER XVI

WATER PRESSURE AND BUOYANCY

IRON, wood, and other substances do not sink through an ordinary solid material, such as a table top, for the simple reason that the particles of the solid table do not move aside and make way for the object to sink through it. The particles of a fluid, however, such as water or air, are capable of moving out of the way, so that an object heavier than the fluid, bulk for bulk, sinks. Thus a piece of iron sinks through water and through air, but a piece of wood does not sink through water, though it does through air, because a certain volume of wood, a cubic foot for example, is lighter than a cubic foot of water, but heavier than a similar volume of air.

Evidently the factor which determines whether an object sinks or floats in a fluid is the weight of a definite volume of the object compared with the weight of an equal volume of the fluid.

Since water is so plentiful on the earth's surface and mankind is so much concerned with it in shipping and other ways, the relation of liquids to solids immersed in them is best illustrated by special reference to water, though it must be understood that the same principles are generally applicable to other liquids.

BUOYANCY AND SHIPPING

As we have just seen, a cubic foot of iron sinks in water, because it weighs more than a cubic foot of water. This fact can be stated in another way. The iron sinks because a cubic foot of it contains more matter than that in a similar volume of water, the matter constituting iron being *denser* than that composing water. The **relative density** of iron is greater than that

of water; the density of water being taken as unity, the relative density of iron is 7·8. It is an easy matter to prove that iron is 7·8 times as dense and as heavy as water, all the evidence required being the volume of a lump of the metal expressed in cubic centimetres and its weight expressed in grammes. Then *by dividing the weight by the volume the relative density is obtained*, as the following example shows. A small piece of iron weighs 10 grammes and its volume is found to be 1·3 cubic centimetres. Now 10 grammes of pure water have a volume of 10 cubic centimetres, and by dividing weight of water by its volume we get 1 as the relative density of water. It requires only 1·3 c.c. of iron to weigh 10 grammes, and by dividing weight by volume we obtain 7·8 as the relative density of iron.

It is easy to weigh a piece of iron, but its volume cannot be determined by measuring length, breadth, and depth when the piece is of irregular shape. In the case of insoluble substances heavier than water, the volume can be found by immersing it in water and noting the displacement. This can be done by means of a measuring glass graduated in centimetres, the levels of the water before and after the immersion of the substance being noted and the difference gives the volume in cubic centimetres.

The weight of any substance, or the force of gravity upon it, is directly proportional to its relative density, hence the term **specific gravity** is used to denote *the ratio of the weight of a substance to that of an equal volume of pure cold water.* Thus the quantity 7·8 represents both the relative density and the specific gravity of iron. Similarly the specific gravity (and relative density) of common glass is 2·5, that of limestone is 2·6, that of lead is 11·36, and so on. These facts can be verified by the method given above.

FIG. 140.—SPECIFIC GRAVITY BOTTLES.

In the case of sand, lead shot, etc., a simple apparatus called a **specific gravity bottle** is used (Fig. 140). The bottle has a glass stopper containing a narrow tube passing through it so that water can flow out of the tube and ensure that the bottle

is completely filled with liquid. The method of procedure is as follows: (1) weigh the sand; (2) weigh the stoppered bottle filled with water together with the sand (outside the bottle) on the same balance pan; (3) place the sand in the bottle, fill up with water and weigh again. This third result will be less than that of (2) since water is displaced by sand, and the loss in weight (*i.e.* 2 - 3) gives the volume of the sand, and the specific gravity is found as usual.

Since specific gravity of a substance

$$=\frac{\text{weight of a definite volume of substance}}{\text{weight of equal volume of water}},$$

that of a liquid can be found simply by filling the bottle with the liquid and weighing, and then by filling the bottle with pure water and weighing again. As the volume is the same in each case, the required specific gravity is the ratio of the weight of liquid to that of water.

We are now in a position to state in more precise terms the reason why an object sinks or floats in water. Any object having a specific gravity greater than that of water sinks in it, but one having a specific gravity less than that of water floats in it.

An iron ship floats because its volume is composed largely of air and light objects occupying the various rooms and spaces. The specific gravity of the ship *as a whole* is much less than that of water, but should a bad leak occur the ship sinks immediately the specific gravity of the whole exceeds that of sea water. A lifeboat composed of very light materials does not sink though it may become filled with water, because the specific gravity of boat plus water still remains less than unity.

It is very necessary to load ships so that there is a sufficient margin of safety; it is dangerous to allow the specific gravity of the whole to approach too near to that of water. Until the year 1890 ships were often overloaded and unable to withstand heavy seas; since they were immersed too deeply in the water there was not a sufficient **freeboard** or part of the ship above the water line. A native of Bristol named **Plimsoll** eventually succeeded in getting it made illegal to load ships so that they floated too low in the water, and now every ship bears a mark called the **Plimsoll**

line which determines the level of its greatest permissible submergence (Fig. 141). Since sea water varies in composition and density, slightly different levels are permitted in different seas.

The cargo-carrying capacity of a ship is represented by a figure called its **tonnage**, an estimate of which is arrived at by dividing the number of cubic feet of space by 100. That of the *Majestic*, the world's largest liner, is about 56,500 tons, and this means that it can carry this amount of material; but a heavier battleship of the super-Dreadnought type, such as H.M.S. *Hood*, can carry only a smaller load of some 40,000 tons because of the great quantities of steel and iron in its construction; it does not require so much additional weight to bring it down to the

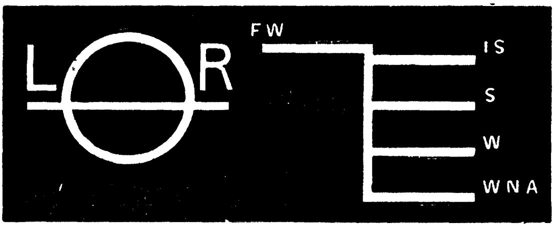


Fig. 141.—The Plimsoll Line

which is marked on the sides of all sea-going vessels. The letter LR refer to Lloyd's Register of Shipping. The lines to the right indicate correct levels for *Fresh Water, Indian Summer, Summer in temperate latitudes, Winter,* and *Winter in North Atlantic.*

Plimsoll line. A **submarine** may be regarded as a ship having a variable and controlled specific gravity. Tanks are arranged fore, aft, and amidships, and by means of water admitted to these the vessel sinks when desired. On the water being expelled again by pumps worked by compressed air, the ship rises to the surface.

The human body has a specific gravity slightly greater than unity, hence to prevent its sinking one of two things must occur. Either it must attach itself to a buoy, so that the specific gravity of body-plus-buoy is less than that of water, or by movements of the limbs in swimming a sufficient upward pushing force is exerted. The motions of arms and legs in swimming force the body upwards as well as move it forwards. As explained below,

such an upward force or *upthrust* is equivalent to a loss in weight.

Owing to the different proportions of dissolved salts in sea water in different regions, the body and other objects vary in buoyancy in various seas. Average sea water has a density of 1·0275, that of the Baltic is less dense than this, but that of the Dead Sea in Palestine is greater, a fact which explains why the human body floats in the Dead Sea. It is much easier to swim

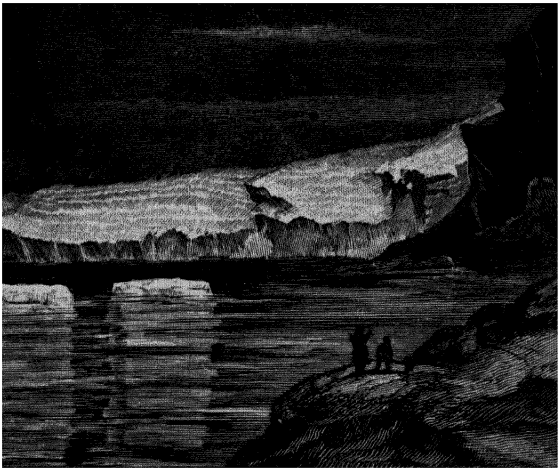


FIG. 142.—ICEBERGS FORMING FROM A GLACIER.
ICE BEING ONLY SLIGHTLY LESS DENSE THAN WATER, MOST OF AN ICEBERG REMAINS BELOW THE SURFACE OF THE SEA.

in salt than in fresh water, because less force is required to prevent the body from sinking.

Since water expands on freezing, ice is less dense than water, consequently it floats, but only about one-ninth of its volume appears above sea-level, the greater submerged portion being a source of considerable danger (Fig. 142). Oils float on water and do not mix with it, a fact which explains the use of oil to make rough water calmer and incidentally is responsible for the saying, 'pouring oil on troubled waters.' It seems that the oil acts as a

lubricant preventing the wind pushing or dragging the water up into dangerous crested waves. It may also suppress small ripples by reducing the surface tension, thus aiding the calming process by giving the wind still less ' grip ' on the water. The fact that oil floats on water is also made use of when it is poured on water containing mosquito larvae ; it prevents the larvae from reaching the surface to breathe, so that they die of suffocation.

HYDROMETERS AND THEIR USES

Liquids such as oil, turpentine, methylated spirit, and alcohol have a relative density less than that of pure water, hence their specific gravities are represented by fractions less than unity. This being the case, an object which just floats in water will sink in one of these liquids. A piece of wood floats in water with part of its substance above the water line, but the same piece of wood is submerged to a greater extent if placed in methylated spirits, hence *the relative amount of submergence of a special object can be used to determine the specific gravity of a liquid*, the special object employed being called a **hydrometer.** This normally consists of a glass tube containing air and correctly weighted with a little mercury at the bottom, so that the instrument floats upright in pure water with so much of it submerged that the correct reading on a scale coincides with the surface of the water. If the instrument is now placed in a less dense liquid, such as turpentine, more of it is submerged and the specific gravity can be read directly from the scale (Fig. 143). Such hydrometers are of two types—those used for ascertaining the specific gravities of liquids lighter than water, and others employed with liquids heavier than water, suitable scales being employed for each purpose.

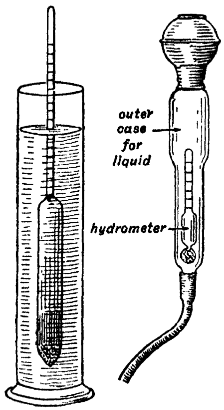


FIG. 143.—HYDROMETERS.

THE FIGURE ON THE RIGHT REPRESENTS A FORM OF INSTRUMENT USED FOR TESTING SPECIFIC GRAVITY OF ACID IN ACCUMULATORS.

There are many practical uses of such instruments, for example, the determination of the specific gravity of acid in an accumulator. When the accumulator is in the fully charged condition the hydrometer indicates about 1·25, but when discharged the acid solution is less dense and the reading is roughly about 1·18. The density of milk can be tested by means of a special hydrometer graduated for the purpose and called a **lactometer.** The average specific gravity of good cow's milk is 1·031. Similarly, other hydrometers are used to determine the relative densities of beer, spirits, etc. Proof spirit is a mixture of water and alcohol having a specific gravity of 0·9198 at a temperature of 15° centigrade. Spirits which are underproof contain less alcohol and consequently have a higher specific gravity.

THE PRINCIPLE OF ARCHIMEDES

It is easy to find the volume of metal or stone by displacement of water on a measuring glass, but how are we to find the volume of a substance such as sand in order to calculate its specific gravity? Another method in which volume can be found by *weighing* is employed, and in order to understand this method we must consider other facts concerning bodies immersed in water.

When a stone or other object is completely submerged it *displaces a volume of water equal to its own volume*, and this displaced water resents the displacement as it were, and exerts a pressure or upthrust, trying to force the stone out of the water again. The force of gravity pulls the stone downwards, but the effect observed is not so pronounced as when the stone is weighed in air, since there is opposition due to the upward pressure of the displaced water. In other words, *the stone loses weight when it is immersed and the amount of this loss is equal to the weight of displaced water.* Now, every gramme of displaced water means one cubic centimetre of volume, hence the loss of weight in grammes equals the volume of displaced water in cubic centimetres, and this equals the volume of the completely submerged object. *The volume of any insoluble solid can be found by noting its loss of weight when immersed in water.* This

relation between the loss of weight and volume, and known as **the Principle of Archimedes,** was discovered by **Archimedes,** a Sicilian mathematician who lived about 250 B.C.

Instead of placing a piece of stone or iron in a measuring glass containing water, its volume can be found by weighing it first in air as usual, and then in water by suspending it with a thread and submerging it in water contained in a vessel supported on a wooden bridge. (Fig. 144). The vessel and water is thus kept apart from the pan of the balance as shown in the illustration.

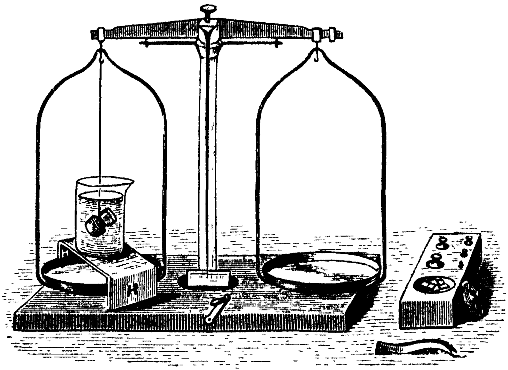


FIG. 144.
AN INSOLUBLE OBJECT MAY BE WEIGHED IN WATER CONTAINED IN A VESSEL SUPPORTED ON A BRIDGE, *H*, ABOVE THE BALANCE PAN.

The Principle of Archimedes enables us to consider the matter of buoyancy from still another aspect. An object sinks as soon as the upthrust due to displaced water is insufficient to keep the object afloat. The Plimsoll line is a means of ensuring a sufficient margin of effective upthrust. It must be clearly understood that when an object sinks the upthrust is still there, but is not successful so far as flotation is concerned.

SOME PRACTICAL CONSEQUENCES OF WATER PRESSURE

The level of water in a vessel is raised when some of it is displaced by an immersed solid. The water raised above the

original level exerts a downward pressure, and this pressure is transmitted in all directions, as explained in the previous chapter. Thus the water in a tank presses as much on the side as on the bottom of the tank. One result of this distribution of pressure is the level or 'horizontal' surface of undisturbed water. In popular language this fact is frequently expressed by the statement that 'water finds its own level.'

Pressure on the sides of anything containing water is responsible for the breaking down of artificial dams and natural embankments called levees with accompanying disastrous floods. If water did not press upon the sides of a tank a hole could be

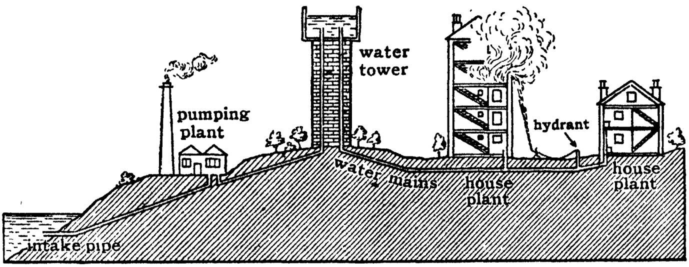
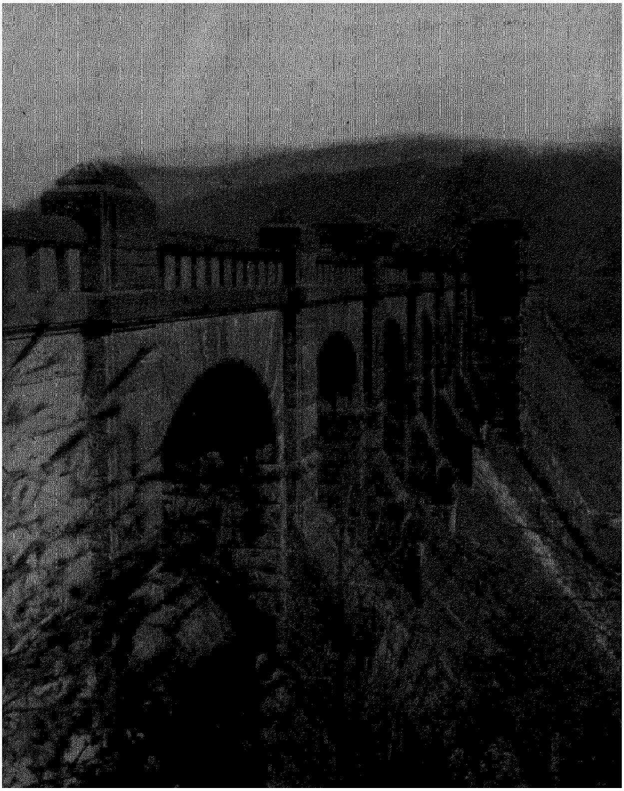


FIG. 145.—DIAGRAM ILLUSTRATING TOWN WATER SUPPLY.

made in the side and the water would not flow out of it. But water does flow through the hole, and if the hole is replaced by a pipe communicating with another empty tank, water will flow from one tank to the other until the water level is the same in both tanks. When this occurs the pressure in the pipe is balanced, that is, water on one side presses as much as that on the other side.

The flow of water from a higher level to a lower one is the result of unequal pressure and is the principle of town water supply. Water is pumped to a large reservoir situated on some hill or land at a higher level than that of the town, consequently all parts of the town receive water at reasonable pressure. (Fig. 145.) In many cases the reservoir is many miles distant and may consist of a natural or artificial lake. For example, the water supply of Liverpool is obtained from Lake Vyrnwy in

North Wales, a lake artificially produced by placing a dam 1180 feet long across the valley of the river Vyrnwy. (Fig. 146.) Manchester obtains its water from Thirlmere, a natural lake in Cumberland.



(*Topical Press.*)

FIG. 146.—SIDE VIEW OF THE DAM, LAKE VYRNWY.

In artesian wells (see Chapter IV), named from a district in France, advantage is taken of the fact that water in porous rocks in the hills is at a higher level than land where the well is situated.

The transmission of pressure through water is of great use in such appliances as the **hydraulic press,** in which a pressure on a small surface of water can produce an equal pressure per square inch on a large surface, thus giving a powerful advantage. Pressure exerted by a piston upon water in a small cylinder produces an equal pressure per square inch upon a much larger piston in a larger cylinder forming the bottom part of a press. It must not be imagined that something is obtained for nothing, however; the smaller piston must be moved through a correspondingly larger distance than the larger one. The case is one of mechanical advantage operated by hydraulic means. The principle of the press is also that of **hydraulic lifts** used in some hotels, etc. The cage of the lift corresponds to the larger piston of the press and is immediately above a long steel shaft supported by water in a very strong cylinder. Water under high pressure passes through a small pipe into this cylinder and the pressure causes the lift to rise. Taps control both the ascent and the descent.

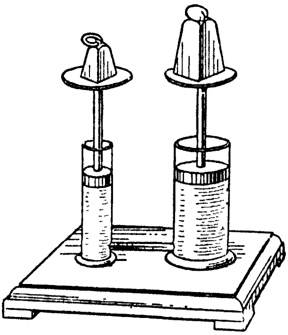


FIG. 147.
BY THE TRANSMISSION OF EQUAL PRESSURE PER SQUARE INCH, A SMALL WEIGHT BALANCES A LARGER WEIGHT.
(By courtesy of Messrs. Townson & Mercer.)

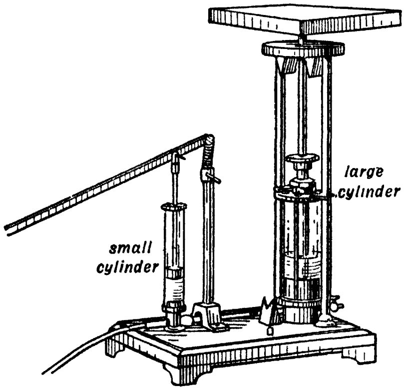


FIG. 148.—THE PRINCIPLE OF THE HYDRAULIC PRESS.
PRESSURE EXERTED BY A PISTON UPON WATER IN A SMALL CYLINDER PRODUCES AN EQUAL PRESSURE PER SQUARE INCH ON A LARGER PISTON.
(By courtesy of Messrs. Townson & Mercer.)

A **hydraulic jack** employed for lifting very heavy bodies, such

as locomotives, is very similar to the press. A lever handle applies pressure to a small water column, and this is transmitted

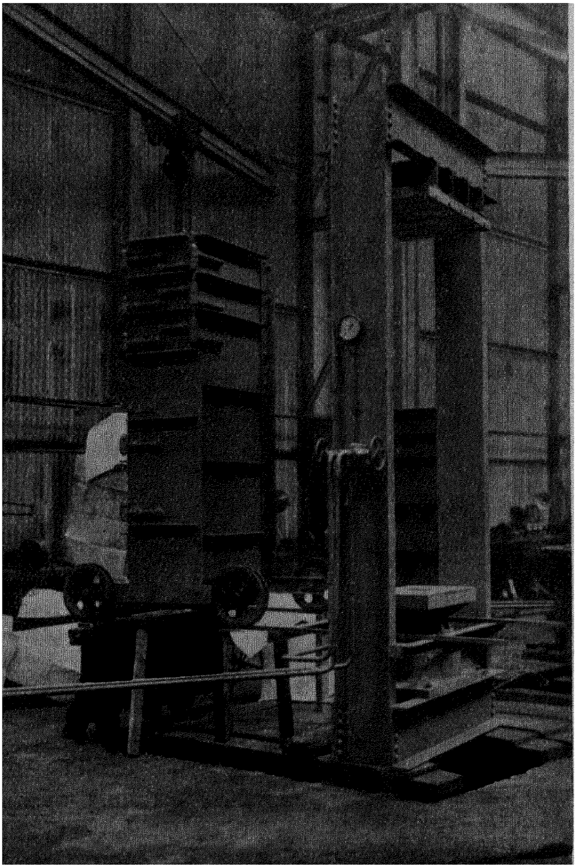


FIG. 149.—HYDRAULIC PACKING PRESS.
THE PRESS IS ON THE RIGHT, AND BALING CASES ARE SEEN ON THE LEFT.
(By courtesy of Hollings & Guest, Ltd.)

to a wider column, above which the end of a cylinder rises as the result of the pressure.

CHAPTER XVII

AIR PRESSURE IN RELATION TO DAILY LIFE

AIR has weight, hence it exerts a pressure upon all objects it touches. The atmosphere extends upwards for many scores of miles, but the upper layers are extremely thin compared with the denser portions near the surface of the ground. The air, as other gases, can be compressed so that under a greater pressure a given weight of it can be forced to occupy a smaller space than it occupies under less pressure. The lower layers of the air have to support the weight of all the air above, hence the greater weight and density of the atmosphere just above the earth's surface. It must not be overlooked that if a pressure is exerted upon air, the air also resists and exerts a pressure against whatever is compressing it. This is noticeable in a bicycle pump; if the connecting tube is closed with the finger, the handle of the pump is forced back by the air in attempting to regain its original volume. So far as volume is concerned, air is elastic (see Chapter XV).

The relation between the pressure upon a gas and the resulting volume is expressed by **Boyle's Law,** which states that *when the temperature remains constant the volume is inversely proportional to the pressure.* If the pressure is doubled, the volume becomes one half its original size, or if the pressure is halved, then the volume is doubled, and so on. **Robert Boyle** (1626-1691), a son of the Earl of Cork, devoted much of his time to the study of the physical properties of air, and was one of the original members of the 'Invisible College' which later developed into the Royal Society in 1663.

Boyle's law can be verified by means of quite a simple apparatus consisting of a long glass tube of uniform width bent in the

shape of a U, but one side much longer than the other. (Fig. 150.) The smaller side is closed but the other is open so that mercury can be poured in as desired. The mercury is at first adjusted so that its level on both sides of the tube is the same, and air in the closed space at the upper part of the shorter tube is then subjected to the pressure of the external atmosphere at the time. Mercury on one side exactly balances that on the other side, hence the only pressure exerted on the enclosed air is that of the atmosphere, and as we shall see later, the average pressure of the air is equal to the weight of a column of mercury 30 inches high. Since the tube is of uniform width, the length l represents the volume of confined air, and if extra mercury is poured in, the pressure upon this air is increased, since the weight of a small column (h) of mercury above the level in the mercury in the smaller side of the tube must be added to that of the atmosphere. When sufficient mercury is added to give a column of about 30 inches higher than the level of the mercury in the shorter tube, the total pressure upon the enclosed air is about double the atmospheric pressure and the length l, hence the volume of enclosed air, is half its original size when the mercury was at the same level in both sides of the tube. The pressure has been doubled and the volume halved.

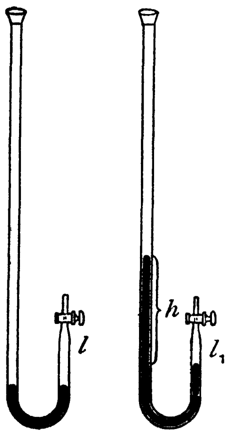


FIG. 150.
SIMPLE APPARATUS FOR THE VERIFICATION OF BOYLE'S LAW.

But it is not necessary to add so much mercury in order to prove Boyle's law, since, if the law is true, the product of the pressure multiplied by the volume gives a constant figure, as a consideration of the following cases shows: if the pressure (P) is 2, the volume (V) is $\frac{1}{2}$, then the product of P and V (PV) = 1; if P = 3, and V = $\frac{1}{3}$, then PV = 1; again if P = 4 and V = $\frac{1}{4}$, then PV = 1, and so on. By placing various quantities of mercury in the longer tube, measuring the difference in level h, and

adding this quantity to the air pressure as shown by a barometer at the time, the total pressure in each case is obtained. Then by measuring the respective lengths (l) of the enclosed air each time the mercury is added the volume is obtained and the value of PV can be found by calculation. Of course it is necessary to express h, l, and the atmospheric pressure in the same units, either inches or centimetres, the latter being used in laboratory work. Any gas obeys Boyle's law, provided the temperature remains constant and that it is not near the temperature at which it liquefies.

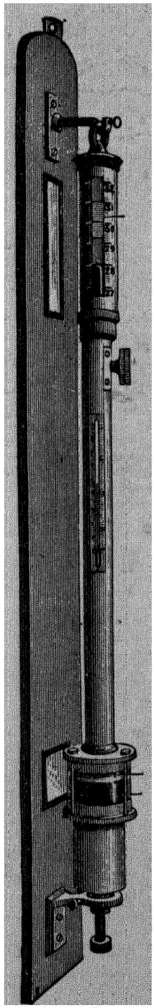


FIG. 151.—FORTIN'S BAROMETER.

HOW AIR PRESSURE IS MEASURED

The pressure exerted by air is of enormous importance in daily life since it largely determines the weather, influences the boiling of liquids, is related to the working of balloons and airships, and operates a great number of mechanical contrivances ranging from a simple pump to vacuum brakes on trains. Since the air pressure varies with conditions of temperature, humidity, and altitude above sea-level it is necessary to have some means of measuring it.

The apparatus commonly used is known as a **Fortin's barometer,** which consists of a glass tube of uniform bore and about one metre in length (Fig. 151). The upper end is closed but the lower end is open, and is placed below the level of mercury in a trough. At first the tube is completely filled with mercury and then inverted and the lower end placed in the trough, a finger preventing the escape of mercury until the tube is safely placed in position. On removal of the finger the mercury column drops until

its weight is exactly balanced by the external air pressure upon the mercury in the cistern. The arrangement is a kind of weighing machine in which a short heavy column of mercury balances a very long column of air which extends upwards as far as the furthest limit of the atmosphere. Note that the column of air is of *the same width or area of cross-section* as the mercury column which balances it, hence the bore of the barometer tube may be of any convenient size. As the air pressure varies, so the height of the barometer column varies correspondingly, and the air pressure is expressed in terms of the height of mercury above the level of that in the cistern, such height being measured in inches or millimetres, whichever is the more convenient.

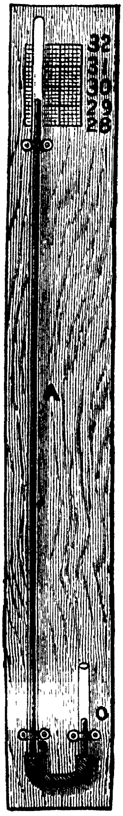


FIG. 152.—A 'SIPHON' BAROMETER.

THE PRESSURE OF THE AIR AT *O* BALANCES THE COLUMN OF MERCURY ABOVE THE LEVEL OF *O* IN THE TUBE *A*. THE AIR COLUMN EXERTING A PRESSURE AT *O* IS OF THE SAME WIDTH AS THE MERCURY COLUMN.

Since the scale at the side of the mercury column of the barometer is fixed it is important that the mercury in the cistern shall be at the correct level, and when necessary it is adjusted by means of a screw underneath which raises or lowers the movable base of the cistern until the point of an ivory pin just touches the surface of the mercury. As the mercury barometer has seldom to measure pressures below that represented by 29 in. of mercury, a scale reading much below this is not necessary. A sliding vernier scale placed against the main scale enables one to read the barometer height accurately to a small fraction of an inch.

For use on board ship a modified form of barometer is mounted so that it remains vertical in spite of the rolling of the ship, and in place of the adjustable cistern is an enclosed iron case containing mercury at a fixed level.

The average or *normal atmospheric pressure at standard sea-level is equal to the weight of a column of mercury 30 inches or 760 millimetres in height*, and it has been accepted generally that the **average level of the tide at Liverpool shall be the standard sea-level,** or ordnance datum (O.D.) in mapping. As one ascends to higher altitudes above sea-level the air becomes less dense, and it has been proved that the barometer pressure usually decreases by one-tenth of an inch (about 2·5 millimetres) for every 90 feet of ascent.

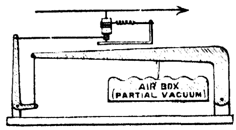


FIG. 153.—THE PRINCIPLE OF THE ANEROID BAROMETER.

THE SURFACES OF THE AIR BOX MOVE INWARDS OR OUTWARDS AS THE EXTERNAL ATMOSPHERIC PRESSURE VARIES.

This relation between altitude and air pressure affords a good means of finding the heights of mountains and levels reached during balloon ascents, but a form of barometer more portable than Fortin's must be used for such purposes. An **aneroid** barometer, as its name implies, is one in which no liquid is used, the air pressure being measured by its effect upon shallow circular metal boxes containing a partial vacuum (Fig. 153). If the air pressure increases, the surfaces of the boxes are pushed slightly inwards; if it decreases the box

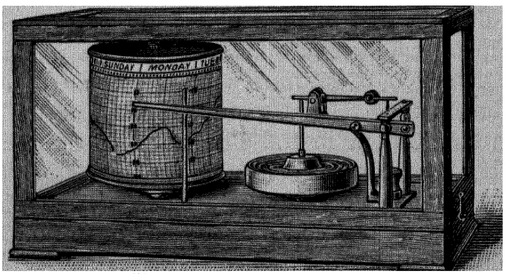


FIG. 154.—A BAROGRAPH.

surfaces move outwards. These movements are communicated to a pointer which moves over a graduated dial indicating air pressures. In larger forms of aneroid barometer several boxes are used so that the movements are increased, and in place of a pointer is a long lever with an attached pen which traces a line

on paper. The paper slowly rotates on a drum operated by clockwork, so that the line traced gives an accurate record of barometric pressures which have existed during a certain time, usually one week. A *self-recording* instrument of this type is called a **barograph,** since it gives a graph or drawing that represents the atmospheric pressure (Fig. 154).

Another reliable type of instrument, called a fisherman's aneroid barometer, is used on small vessels where a large ship's barometer containing mercury would be unsuitable.

AIR PRESSURE AND WEATHER

In most cases fine dry weather accompanies a relatively high pressure, and wet squally weather is associated with comparatively low air pressure, consequently the barometer is usually high with fine weather and low with wet weather, but though this is general, it is not always the case. When rain is likely, the air contains a considerable amount of water vapour, and such *damp air is lighter than dry air.* At first sight this appears strange since water is heavy, but the air contains water *vapour,* and this is lighter than air. Consider the matter in this way. If you have a cubic foot of dry air and then take away some particles of dry air, and in their places put particles of water vapour, you place a lighter substance where there was a heavier one, and the cubic foot of gas loses weight.

Air pressure is thus related to its **humidity,** or the relative amount of water vapour in it. The study of the weather or **meteorolŏgy** is a very complicated subject, and weather forecasts of any real value can be made only by experts supplied with sufficient data, but we can notice briefly one or two outstanding facts concerning air-pressure systems. Weather charts containing information regarding air pressures, temperature, winds, humidity, the state of the sky, etc., are issued daily by the **Meteorological Office.** Air pressures are shown on charts by continuous lines called **isobars**; each isobar is drawn to pass through all places with equal air pressure at the same time. The way in which these lines are related to one another is of great importance, since it gives an idea of the general air-pressure

arrangement existing at the time, and it is the type of pressure arrangement that normally determines the kind of weather experienced. Among the various kinds of pressure arrangements two types, **cyclones** and **anticyclones,** are of great importance and of common occurrence.

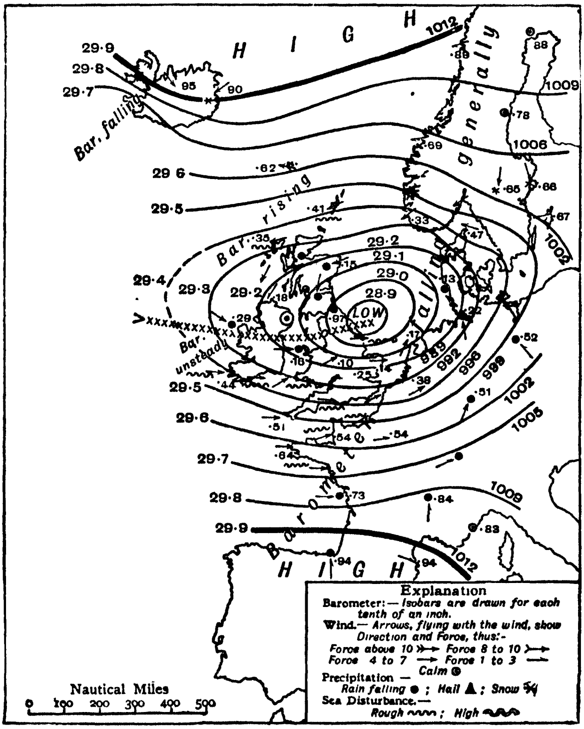


FIG. 155.—A WEATHER CHART ILLUSTRATING A CYCLONE SITUATED OVER THE BRITISH ISLES.

In a cyclone, which often extends over an area as large as Wales, the air pressures are arranged in roughly circular or oval form as represented by isobaric lines (Fig. 155). The centre of the system is a *low*-pressure area, the pressure increasing outwards in all directions. Since air flows from areas of high pressure to those of lower pressures, the winds of a cyclone blow

in towards the centre, their direction being spiral and anticlockwise on account of the earth's rotation. The air motion is somewhat similar to the spiral movement of the last portions of water escaping down the outflow pipe of a sink. The weather

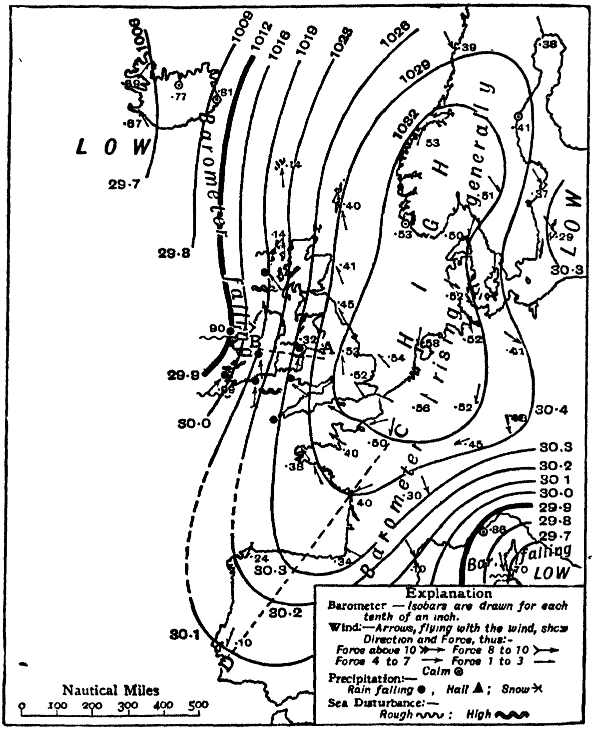


FIG. 156.—A WEATHER CHART SHOWING AN ANTICYCLONE OVER THE NORTH SEA.

accompanying a cyclone is wet, squally and cool in summer, but relatively warm and wet in winter.

In the latitudes of the British Isles these and other pressure arrangements move slowly across Europe from southwest towards the northeast, and take their weather with them, hence the weather Great Britain experiences to-day is frequently ex-

perienced by Scandinavia or the Netherlands in the course of a day or two.

The term cyclone is sometimes used to denote also **tropical revolving storms** or typhoons, in which the area embraced is relatively small, the centre of comparatively very low pressure, and the winds consequently very powerful. Such whirling systems move rapidly and cause great damage.

On modern weather charts air pressure is expressed in units called **millibars,** related to centimetres. A bar is equivalent to a pressure of 29·52 inches of mercury, and millibars are thousandths of a bar; 1015 *millibars are equivalent to the pressure of* 30 *inches of mercury.*

In an anticyclone the air pressure arrangement is the converse of that in a cyclone, the centre being an area of *high* pressure, and the pressure decreases outwards, consequently the winds blow spirally outwards from the centre in a clockwise direction (Fig. 156). An anticyclone frequently covers large areas, moves relatively slowly, and is associated with fine warm weather in summer and fine cold frosty weather in winter.

In all air pressure systems the force of winds depends upon the rate at which the air pressure changes. When the isobars on a chart are near together the change of pressure is rapid and the wind strong, but if the isobars are widely separated, the winds are less powerful. Just as altitude increases rapidly on a hill of steep gradient, so air pressure increases or decreases rapidly in areas where there is a steep **barometric gradient.**

AIR PRESSURE MECHANISMS

Air pressure capable of supporting a column of mercury 30 inches high presses upon everything with a weight of about 14·7 lb. per square inch. A page of this book has an area of about 30 square inches, so that the total weight of air pressing upon it is more than four hundredweight. Let us consider some practical consequences of this pressure. In the first place, why are we not pressed flat against the ground? If you blow up a football bladder it swells equally in all directions and assumes a spherical form. Should the air press forwards only, the football

would assume the shape of a sausage and not that of a sphere. Air presses equally in all directions, the downward pressure due to its weight being transmitted sideways and upwards as well. As we have seen in a previous chapter, this is characteristic of fluids. Our bodies are pressed equally in all directions, hence we remain as we are. Even the air in our lungs, when filled, exerts a pressure equal to that of the outside atmosphere, otherwise breathing would be impossible. A large travelling trunk possesses a lid having an area of about one square yard or 1296 square inches, and this means that the air normally exerts a pressure of no less than 8½ tons on the lid, so that a powerful

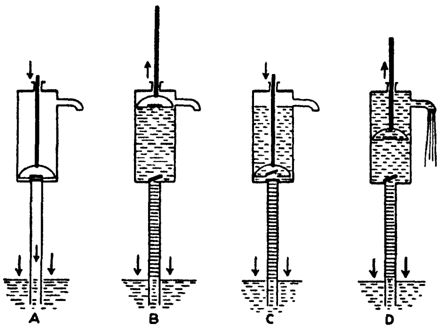


FIG. 157.—THE SIMPLE WATER PUMP.
THE SECTIONS REPRESENT THE CONSECUTIVE RESULTS OF THE FIRST TWO COMPLETE STROKES OF THE PISTON.

crane would be required to lift the lid if the air pressure were not also exerted sideways and upwards.

It is not surprising that such pressure is used for many domestic and commercial purposes. A barometer could be constructed to use water in place of mercury, but the tube would have to be at least 33 feet in height. Instruments of this kind have actually been tried, but they are inconvenient, and there are other reasons, such as evaporation, which make water unsuitable for barometric purposes. Nevertheless the average air pressure can support a column of water nearly 34 feet high, and this means that *theoretically* an ordinary 'suction' **pump** can raise water from a well provided that the distance through which the water

has to be raised is not greater than this. In actual practice, however, it is found that such pumps work efficiently only when the distance does not exceed 28 feet.

In an ordinary pump a piston is moved upwards in a cylinder and the outside air pressure presses water upwards to occupy the space which would contain a vacuum if the water did not follow the piston (Fig. 157). In common language the water is said to be 'sucked' up, but in reality it is pushed up.

When the piston reaches the top and then commences a downstroke, a valve at the bottom of the cylinder closes, but another valve in the piston itself opens and permits the water to pass to the space above. On the next up-stroke this water is ejected through the outlet pipe at the same time as more water is drawn into the cylinder.

Water is pumped from wells of greater depth by means of special apparatus which raises water by suction for the first 25 feet and then lifts a column of water for the rest of the way. In other words, the pump placed low down in the well is fitted with a long vertical delivery tube which enters the pump *below* the piston and is provided with a valve preventing water running back into the pump. An arrangement of this type which forces water in a tube to any desired height is known as a **force pump.**

In the earlier type of **fire engine** operated by steam, a continuous flow of water was ensured by the pressure of air in a vessel, otherwise the stream of water would have been spasmodic. The latest type of fire engine is operated by a petrol motor and specially designed pumps eject a continuous stream of water.

An apparatus simpler in construction than a pump, but by no means so simple to describe, is a bent tube called a **siphon.** This is used for the transference of liquid from one vessel to another, or for emptying a liquid from a container. The tube is first completely filled with the liquid and then one end is submerged in the containing vessel. The liquid then flows out at the further end of the tube until the vessel is empty or until the liquid comes to the same level in a second vessel as it is in the original container.

The action of a siphon may be understood by reference to Fig. 158. In the case of the U-tube to the left the pressure at

the top is balanced and there is no flow of liquid. In the case of the U-tube to the right the pressure at the top is not balanced. At the top of the left hand limb of the tube the pressure is that of the atmosphere less that due to 30 inches of mercury, *i.e.* the pressure is practically nil. But at the top of the right-hand limb the pressure equals that of the atmosphere less that of only twelve inches of mercury, hence there is a pressure forcing the liquid in the direction shown by arrows.

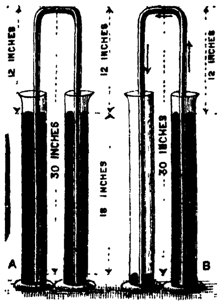


FIG. 158.—EXPLANATION OF A SIPHON.

THE PRESSURE AT THE TOP OF THE U TUBE TO THE LEFT IS BALANCED, BUT THAT AT THE TOP OF THE TUBE ON THE RIGHT IS NOT BALANCED.

Another practical application of air pressure is the **vacuum brake** used on railway trains (Fig. 159). This consists of a piston working in a cylinder and connected by a long train pipe to the engine pulling the train. A current of steam from the engine produces a vacuum in the train pipe and in the space below the piston. When air is permitted to enter the train pipe it also presses upon the underside of the piston but *not* upon the upper side, consequently the piston is forced upwards and the attached brakes are put on. After the brake has been applied, the engine again produces a vacuum by pumping air from the train pipe in order to take the brake off again.

The mode of producing the vacuum in the train pipe is interesting, as it illustrates the way in which a vacuum may be produced for some other purposes. A current of steam moving rapidly under pressure passes an aperture in the train pipe and, producing there reduced pressure, it pulls air from the pipe along with it. Such an arrangement is called an **ejector.**

A very high degree of vacuum such as that required to pump out air from certain forms of scientific apparatus, an X-ray tube for example, can be produced by the ejector principle, but mercury is used in place of steam. Mercury is allowed to fall through a tube, and as it does so, it pulls along with it bubbles of air obtained from another side tube connected to the vessel to be exhausted. More mercury can be added and the process con-

tinued. In this way an extraordinary degree of vacuum can be obtained, far more than that possible when an ordinary air pump is employed.

As a typical example of apparatus used in ordinary laboratory demonstrations, the **Hawksbee air pump** may be quoted. In this there are two cylinders containing pistons in such a way that as one piston is descending the other is ascending. The pistons communicate by a pipe with the glass or other vessel

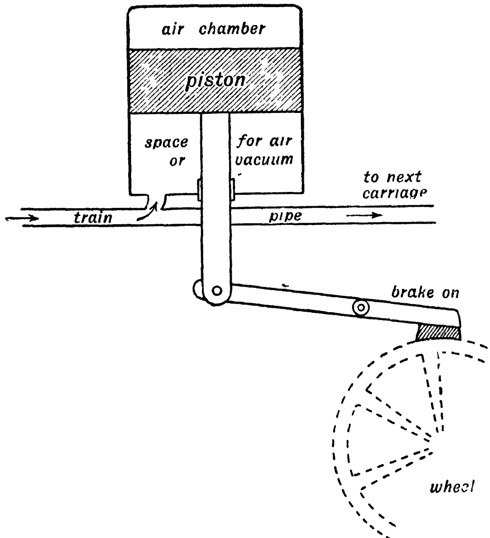


FIG. 159.—DIAGRAM REPRESENTING THE PRINCIPLE OF THE VACUUM BRAKE USED ON TRAINS.

from which the air is to be pumped. Each piston is fitted with a valve which allows air in the cylinder to be passed out on the down-stroke. An up-stroke of either piston draws air from the vessel into the corresponding cylinder and the process can be repeated several times. In working the apparatus a person uses his force against the pressure of the atmosphere on the upper sides of the pistons.

The ordinary atmospheric pressure is responsible for the correct working of railway signals in some methods of signalling.

Pipes connect the signals with the signal box, and since a signal is kept in the down or all clear position by air pressure in the pipes, a failure leaves the signal at the danger position.

The cases we have considered above afford examples of air employed at ordinary pressure, but many useful applications are operated by compressed air. As examples may be quoted compressed air drills, used in quarrying, street repairs, etc., the conveyance of telegrams along pneumatic tubes in post offices, and the **Westinghouse brake** employed on some trains. Such appliances require extra power and special machinery called air compressors, which force air to occupy a smaller volume and exert a greater pressure than is normally the case.

An **aeroplane** must be considered as a mechanism operated by the force of air pressing against the wings and certain movable parts. Just as a swimmer causes an additional upthrust in water by the movements of his limbs, so the aeroplane pulled through the air by its propeller causes the pressure on the wings to give a powerful upthrust, lifting and maintaining the machine in the air. As in the case of objects in water, an upthrust is equivalent to a loss in weight. The movable parts at the tail end of the aeroplane modify the pressure so that the machine ascends, descends, or turns sideways according to the will of the pilot.

CHAPTER XVIII

HEAT AND HOW IT IS MEASURED

In ordinary language, energy signifies capability or strength of action: in science, it is defined as the power of doing work. Heat does work when it changes water to steam which operates a locomotive; therefore heat is regarded as a form of energy. There is a definite relation between the amount of heat and the work performed, as we shall see in the next chapter.

One of the best known books of the famous physicist, **John Tyndall** (1820-1893), is entitled, *Heat, a Mode of Motion*; and it is certain that heat is a motion of the minute particles composing a substance—the hotter the substance is, the more rapidly the particles move. In a cool piece of iron the particles are already in motion, but if the iron be heated the movement of the particles is greatly increased.

The motion and energy of heat may be produced in a variety of ways, some mechanical, some electrical, others chemical, and so on. The heat produced when primitive man kindled a fire by rapidly rubbing pieces of wood together, and that developed when a rifle bullet is stopped suddenly by an armour plate, are examples of heat due to mechanical means. Friction between the parts of a machine is another, and in this case the heat produced represents a loss of effective energy, hence the necessity of oil and grease to lessen the friction. Whereas primitive man wanted the friction, the modern engineer does not. When an electric current flows along certain wires in an electric cooker, the energy of electricity is changed to heat because the wires oppose the current and become red hot in consequence. Opposition generally means the production of heat. In a coal fire and in an oil stove, energy of chemical action is being transformed to

heat and usually light as well. The carbon in coal and in oil combines so eagerly with oxygen in the air, or burns so readily, that much heat is developed by the chemical action. Slow chemical action, such as the rusting of iron, is not usually accompanied by any appreciable development of heat.

Light rays from the sun or other sources are accompanied by heat rays, and if these are focussed by a lens or ' burning glass ' to a small spot upon some thin paper, the concentrated heat rays cause the paper to burn. Attempts have been made to focus sufficient of the sun's rays to boil water, generate steam, and work an engine, but these ventures cannot compete successfully with other means of producing power.

The converse of these changes are of common occurrence and of great use. Heat can be made to do mechanical work, as in the locomotive already mentioned; it can be changed into electricity, as in an apparatus called a **thermopile**; it is often instrumental in promoting chemical changes between substances which will not react when they are relatively cool; and in any of the common sources of light—candles, oil, electric lamps, and gas burners—considerable heat is necessary for the substance to become luminous.

One form of energy can be converted to another, and though naturally no energy is really destroyed, in practical applications there is always some loss when a transformation of energy is accomplished. If it were not so, engines would have an efficiency of 100 per cent., but this is far from being the case. A great deal of energy is dissipated, or escapes being harnessed for practical purposes, and such dissipated energy is mostly in the form of heat. That produced by friction in parts of machinery is an example.

SOME CONSEQUENCES OF EXPANSION AND CONTRACTION IN SOLIDS AND LIQUIDS

Heat being a mode of motion of the minute particles composing a substance, it follows that when a substance becomes hotter the particles require more room for their increased motion. The very obvious result of this is the expansion of the heated material;

the more heat supplied, and the higher the temperature rises, the more the material expands.

In the case of most substances a rise in temperature leads to expansion and if the heating process be continued sufficiently, the particles will obtain more and more room for their movements and the substance if solid will liquefy, and if liquid will become gaseous. The substance changes its physical state; but more will be said about this later. Most substances expand by a definite amount for every degree the temperature is raised, and

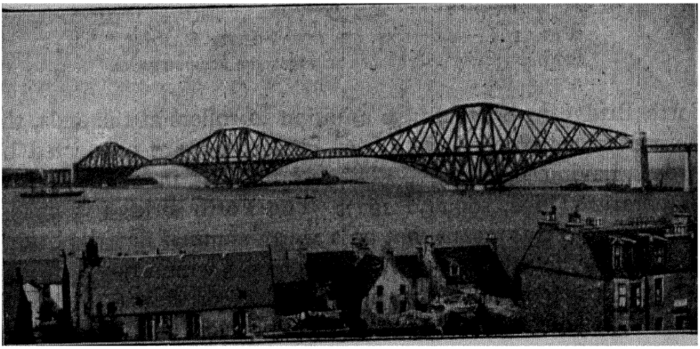


FIG. 160.—THE FORTH BRIDGE.

in the case of solids and liquids the amount that one substance expands for one degree is not usually the same as that for a different substance. Thus, for a given rise in temperature, a piece of brass expands a little more than a piece of copper of the same size, and much more than a piece of steel of the same initial volume. The actual increase of size for each degree of temperature is very small. A steel rod one yard in length at 0° Centigrade would be 1·000011 yards at 1° C., and 1·0011 yards at 100° C. The quantity 0·000011 is called the **coefficient of linear expansion** of steel, since it represents the fraction of the original length at 0° C. that a rod of steel will expand for every degree Centigrade its temperature is raïsed. The coefficient of surface expansion is about double, and that of volume expansion is roughly three times the linear coefficient.

These quantities are quite small, but nevertheless of some

practical importance. A sufficiently large space must be left between two portions of a railway line to allow for expansion in hot weather, otherwise the rail would be badly buckled. Steel bridges are so constructed that allowance is made for changes in temperature at different seasons. Usually the ends of the bridge rest on rollers, but in very large structures, such as the

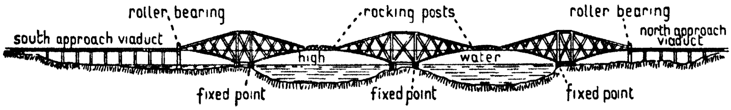


FIG. 161 —SECTION OF THE FORTH BRIDGE.
SHOWING POSITIONS OF ROLLER BEARINGS AND ROCKING POSTS.

Forth Bridge in Scotland, in addition to rollers at the ends, the main portions of the bridge, the cantilevers, are connected by girders having 'rocking posts' which assist in adaptation to temperature (Figs. 160 and 161). The Forth Bridge is 5349·5 feet long, and this means that on a warm summer day the bridge is nearly one foot longer than it is on a cold winter day.

Iron pipes meant to convey hot water or steam should be fitted with some device permitting expansion and contraction.

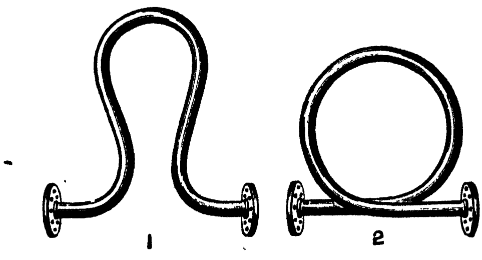


FIG. 162.—EXPANSION BENDS.
THESE INSERTED BETWEEN LENGTHS OF PIPING PERMIT THE PIPES TO EXPAND AND CONTRACT WITH CHANGES OF TEMPERATURE.

Changes in length are permitted by the use of expansion joints or by expansion bends (Fig. 162). The former consists of a gap between two portions of piping, with a surrounding collar tube above the gap and the ends of the piping, and the latter consists of curved pieces of tubing which act as springs.

Changes in temperature also affect the length of a pendulum in a clock or the diameter of a balance wheel in a watch. A clock keeps correct time if its pendulum retains its proper length, and a watch marks time properly if the diameter of its balance wheel remains the correct size.

Various devices have been employed to compensate for expansion and contraction in clock mechanisms. In **Graham's mercurial pendulum** (Fig. 163), mercury in a vessel or vessels expands upwards as the main rod of the pendulum expands downwards, and if the mercury column is of the correct length, the two effects are nicely balanced. **Harrison's gridiron** pendulum consists of several steel rods alternating with others composed of brass, and so arranged that as the steel rods expand downwards, those of brass expand upwards to the same extent. Consequently the centre of the bob is neither lowered nor raised, and this is the thing which really matters as far as time keeping is concerned. There is bound to be an extra steel rod, the middle one supporting the bob, hence the use of the more expansive brass for the other set of rods.

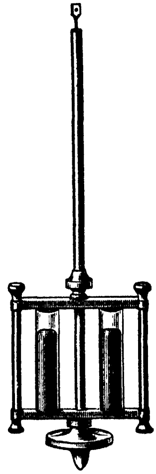


FIG. 163. GRAHAM'S MERCURIAL PENDULUM.

The invention by the French physicist, M. Guillaume, of an alloy of steel and nickel named **invar**, has rendered the use of these rather cumbrous modes of compensation unnecessary. This alloy expands or contracts by such small amounts that its length is for practical purposes invariable for ordinary changes of temperature due to the weather, hence the name "invar," an abbreviation of invariable. Its coefficient of linear expansion is only 0·0000009.

The balance wheel of a watch is caused to oscillate by a fine steel hair-spring, and if by reason of a rise in temperature the wheel becomes bigger, its motion is slower and the watch loses time. Conversely, by a fall of temperature it may move too quickly. In order to prevent such temperature effects the balance wheel is composed of two metals, one more expansible

being outside the other. Three arms or spokes support the circumference, and there is a gap in the circumference near each spoke. When the spokes expand outwards the more expansible metal of the circumference causes the further end of each arc to curl slightly inwards, so that the average diameter of the wheel is kept constant.

The examples described show that expansion is generally a nuisance, but this is not always the case. Old buildings, the walls of which exhibit a tendency to fall outwards, can be strengthened by long iron bars extending from one wall to that on the other side and fastened externally by cross-bars and nuts screwed up tightly while the bar is hot. Then the enormous force of contraction on cooling pulls the walls slightly together. The iron rim of a cart-wheel is put on hot, so that it fits tightly when it is cold.

This is the general rule, but there are one or two exceptions, the most notable being the contraction of water when heated so that the temperature rises from 0° Centigrade to 4° Centigrade. The reverse also holds good ; that is to say, water expands when cooled from 4° to 0° Centigrade. Above 4° Centigrade water expands on being heated. (The Centigrade scale of temperature is that mostly used in scientific work, and with other scales it is described below.) From what has been said about the expansion and contraction of water, it is clear that *water is at its maximum density at* 4° *C*. One result of this is that the gramme—the unit of weight in the metric system—is accurately the weight of one cubic centimetre of pure water only when the water is at this temperature. The water at the bottom of a pond in winter may be one or two degrees above 0° Centigrade, though the surface layers are frozen, a fortunate circumstance for living creatures inhabiting the pond. Other substances which expand slightly on solidification are cast iron and type metal (Chapter XL.).

THERMOMETERS AND THE INDICATION OF TEMPERATURE

Temperature is the degree of hotness of a body, and heat passes from a hotter body having a higher temperature to a cooler body having a lower temperature.

In scientific work where exact measurements of temperature are necessary, thermometers are of much use, and in daily life these instruments are employed in a variety of ways. The more modern types of electric ovens are fitted with thermometers specially designed to register high temperatures ; others of more simple design are employed in public buildings, swimming baths, hydropathic establishments, and in horticultural work. In medical practice a special clinical thermometer is of frequent use, since a rise in blood temperature of only two or three degrees means that a person is suffering from one of the many forms of fever (Fig. 164).

The action of a thermometer is based upon the fact that a liquid expands by a definite fraction of its original volume for every degree through which the temperature is raised. The

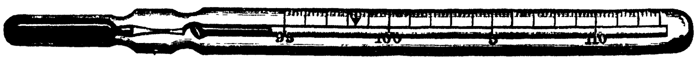


FIG. 164.—A CLINICAL THERMOMETER USED BY PHYSICIANS.

liquid generally employed is mercury, the coefficient of volume expansion of which is 0·000182. Thus a cubic centimetre of mercury at 0° C., becomes 1·000182 c.c. at 1° C., and 1·0182 c.c. at 100° C. These figures represent the **real expansion** of mercury after allowance has been made for the expansion of the vessel in which the liquid is contained. The visible expansion of mercury in a thermometer is called the **apparent expansion,** that of the containing vessel making it slightly less than the real expansion. But since we require in everyday life an instrument which will indicate changes in temperature and not coefficients of expansion, an ordinary thermometer which shows a regular increase in length of a thread of mercury corresponding to a steady rise in temperature answers our purpose very well.

Mercury in a glass bulb expands on being heated, and rises in a tube of very narrow bore compared with the size of the bulb, and often crescent-shaped in section, consequently a small expansion of the mercury produces a visible effect in the narrow tube.

When a thermometer is being made, air is expelled from the bulb by heat and then sufficient mercury is ‘ sucked ’ in to fill

the bulb and a small portion of the tube. In order to make a scale of temperature, at least two positions of the mercury corresponding to two widely different temperatures are required. The lower *fixed* point, as it is called, is usually obtained by placing the bulb in melting ice placed in a funnel so that water can be drained away (Fig. 165). When the position of the mercury in the bore becomes steady, a mark is made upon the glass and that point is called 0° on the **Centigrade** scale, invented by **Celsius** in 1742, and on the scale of **Réamur**, also used in Continental Europe. But on the **Fahrenheit** scale, used domestically in the British Isles, this point is called 32°, Fahrenheit obtaining his zero position by using a mixture of salt and ice. For the upper fixed point all three scales now use the position of the mercury when the thermometer is placed in the steam being produced from water boiling at normal atmospheric pressure.

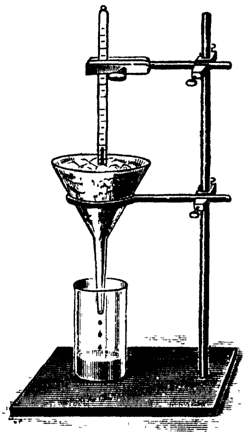


FIG. 165.
THE METHOD EMPLOYED TO *FIND THE LOWER FIXED POINT* OF A THERMOMETER.

This upper point is called 100° Centigrade, 80° Réamur, or 212° Fahrenheit as the case may be. When the upper fixed point has been found, the thermometer tube is sealed by heat and the length of tubing between the fixed points is divided into an equal number of subdivisions or degrees, the actual number of which depends upon the scale chosen. It is clear that

$$100^\circ \text{ C.} = 80^\circ \text{ R.} = 180^\circ \text{ F.},$$

the 32° below the temperature of melting ice being ignored in the case of Fahrenheit (Eig. 166).

A reading on one scale can be converted to the equivalent reading on either of the other scales without difficulty. Thus, to convert 40° C. to the equivalent reading on each of the other scales:

$$40^\circ \text{ C.} = (40 \times \tfrac{80}{100}) = 32^\circ \text{ Réamur,}$$

and

$$40^\circ \text{ C.} = (40 \times \tfrac{180}{100}) + 32 = 104^\circ \text{ Fahrenheit.}$$

Note that in the latter case the 32° below the Centigrade zero must be added. Consider the reverse of this last example. What is the Centigrade reading corresponding to 104° F.? The 32° below Centigrade zero must first be subtracted, leaving 72°.

$$104^\circ \text{ F.} = (104 - 32) \times \tfrac{5}{9} = (72 \times \tfrac{5}{9}) = 40^\circ \text{ C.}$$

Examples of instruments designed for special purposes are the **clinical** thermometer used by physicians, and the self-registering **maximum** and **minimum** thermometers employed by gardeners and by meteorologists for obtaining temperatures of the air for weather reports.

In the clinical thermometer there is a narrow constriction which allows the mercury to pass forwards under the pressure of expansion, but prevents it from going back again, hence the temperature can be read after the instrument has been removed from the patient. The mercury is brought back to its original position by jerking the thermometer. The scale indicates degrees extending from 95° F. to 110° F., the normal blood temperature being 98·4° F. Few people survive after reaching a temperature of 106° F., and general weakness may be accompanied by a temperature slightly below normal.

The clinical thermometer is a variety of maximum thermometer, but that used by gardeners and weather experts is of a larger and more robust type. A small steel index in the bore of the tube is pushed along by the mercury as it expands, and it is obvious that the nearer end of

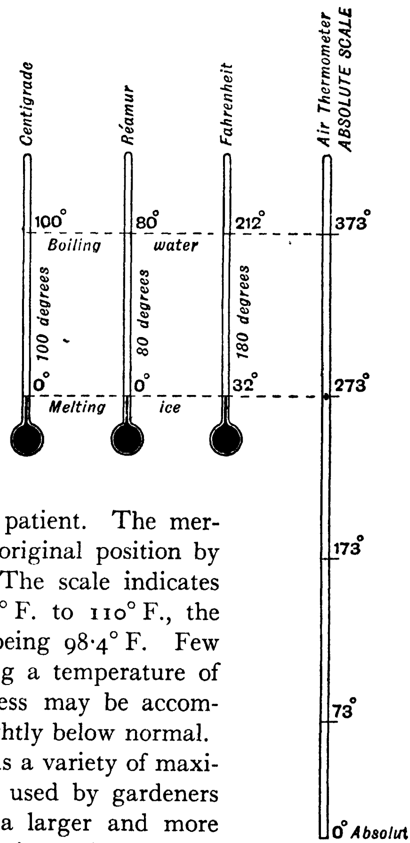


FIG. 166.
DIFFERENT THERMOMETRIC SCALES.

this index will be left at the highest degree mark reached by the mercury. A small magnet can be used to draw the index back again when desired. In a **minimum thermometer** alcohol is used in place of mercury, and a small index is placed in the alcohol. The liquid flows past the index on expansion but drags the index back with it on contraction, hence the index registers the lowest temperature reached during the night or other period of time.

Instruments used in connection with meteorological work are placed in white screens composed of laths of wood resembling venetian blinds. This box-like arrangement is known as a **Stevenson's screen** and allows air to circulate freely through it, but prevents direct sunshine from affecting the instruments, since shade temperatures only are required.

EXPANSION OF GASES

When the same initial volumes are heated, it is found that alcohol expands much more than mercury for the same increase of temperature ; thus different liquids have different coefficients of expansion, though sometimes two or more liquids may approach very closely in this respect. The coefficients of water and mercury are almost the same. Similarly with solids, the coefficients of expansion differ, but *gases all have the same coefficient of expansion* ; they all expand by the same amount for a given rise of temperature, provided the pressure on them remains constant, and that they are not near the temperature at which they liquefy.

The relation between the volume and temperature of a gas is expressed by **Charles's Law,** which states that *at constant pressure any gas expands* $\frac{1}{273}$ *of its volume at* 0° *C. for every degree Centigrade the temperature is raised.* Thus, if the volume at 0° C. is 273 c.c., at 1° C. it will be 274 c.c., and at 100° C. the volume will be 373 c.c. Similarly going down the scale, at − 1° C. the volume will be 272 c.c., at − 100° C. it will be 173 c.c., and so on. What will it be at − 273° C.? Theoretically there will be no volume at all, but as a matter of fact all known gases liquefy before they reach this very low temperature. There is another

scale of temperature known as the **Absolute scale,** and on this the zero or 0° Absolute is equal to −273° C. Absolute zero really means no temperature at all, but even in the production of very low temperature necessary for the liquefaction of air (see Chapter XXXIII), we have not quite reached the bottom of the scale.

What happens if a volume of gas enclosed in a strong metal vessel of definite size is heated strongly? The gas cannot expand, but its pressure increases as the temperature rises, and this increase in pressure at constant volume also conforms to Charles's Law. *For every degree Centigrade (or Absolute) the pressure increases by* $\frac{1}{273}$ *of the pressure at 0° C. provided the volume is kept constant.* The enormous increase of pressure at constant volume is used in steam engines of all kinds, super-heated high pressure steam being taken by strong tubes to pistons or turbines as the case may be.

TEMPERATURE AND QUANTITY OF HEAT

Temperature is one thing, quantity of heat is another. Heat quantity can be measured in definite units, and the amount of heat in a gallon of water at 15° C. is much greater than that in a 1 lb. iron weight at 50° C. But if we place the iron weight in the gallon of water, heat passes from the hotter weight to the cooler water until both are at the same temperature. Evidently the terms hotter and cooler refer to temperature conditions, and temperature in heat corresponds to water level in hydrostatics. If it has the chance, heat will always pass from a substance having a higher temperature to one at a lower temperature irrespective of the actual quantities of heat in each substance.

The mercury in a thermometer expands because it receives heat from a substance having a higher temperature than it has itself, and the transference of heat and consequent expansion of the mercury continue until the temperature of the thermometer is the same as that of the substance. Thermometers measure temperature, not quantity of heat. When we wish to measure heat quantity we use a **calorimeter,** which is simply a small cylindrical copper vessel for holding water (Fig. 185). The scientific

unit of heat quantity is called a **calorie** and is that amount of heat required to raise the temperature of one gramme of pure water 1° C. Thus the heat required to raise the temperature of one gramme of water 100° is 100 calories, and to raise 100 grammes 1° also requires 100 calories. Water loses similar quantities of heat as it cools; for example, 100 grammes of water in cooling from 100° to 0° give out 10,000 calories.

It is quite easy to calculate the final temperature of the mixture when a certain quantity of hot water is mixed with another quantity of cold water. Find the final temperature when 60 gm. of water at 20° C. are mixed with 30 gm. of water at 80° C. Now if x represents the final temperature, it is clear that the 60 gm. are raised through $(x - 20)$ degrees, and the 30 gm. of hot water lose $(80 - x)$ degrees. Equating heat gained against heat lost, we have:

$$\begin{array}{ll} \text{Heat gained.} & \text{Heat lost.} \\ 60(x-20) & = 30(80-x) \\ 60x - 1200 & = 2400 - 30x \\ 90x & = 3600 \\ x & = 40. \end{array}$$

The final temperature is 40° C. The only apparatus required for this is a calorimeter, thermometer, and of course a balance for weighing the water. The calorimeter will take a little of the heat so that the practical result will not quite agree with the theoretical result given above.

Now, if 30 gm. of iron at 80° C. were used in place of the hot water, the result would not be the same; the temperature would be much lower than 40° C., in fact it would be about 23° C. This is because the same weight of iron in cooling through the same number of degrees gives out far less heat than water does. Iron also requires far less heat than water does to raise its temperature the same amount when equal weights are used. These facts are stated simply by saying that *water has a much greater capacity for heat than iron has*; in fact, water has a greater capacity for heat than nearly all other substances. At constant pressure the gas hydrogen has a capacity greater than that of water. *The ratio of the capacity for heat of a*

substance to that of an equal weight of water is called the **Specific Heat** *of the substance.* If the specific heat of water be taken as unity, then that of most other substances is represented by fractions.

The specific heat of iron is 0·114, and this statement means that one gramme of iron in cooling 1° C. loses only 0·114 of a calorie. Now we are in a position to see why the final temperature in the problem above is about 23° C. when 30 gm. of iron is used in place of hot water. As before, x represents the final temperature. In this case heat gained = heat lost.

$$\begin{aligned}
&\text{Heat gained.} && \text{Heat lost} \\
&60(x - 20) &&= 30(80 - x) \times 0{\cdot}114 \\
&60x - 1200 &&= (2400 - 30x) \times 0{\cdot}114 \\
&60x - 1200 &&= 273{\cdot}6 - 3{\cdot}42x \\
&63{\cdot}42x &&= 1473{\cdot}6 \\
&x &&= 23{\cdot}2^\circ \text{ C.}
\end{aligned}$$

Other problems on specific heat may be worked in this way; the specific heat of a substance can be found if all the other quantities are known.

The list below gives the specific heats of some common substances.

Water	1	Ice	0·471
Alcohol	0·62	Aluminium	0·214
Turpentine	0·42	Iron	0·114
Mercury	0·033	Copper	0·095

Differences in specific heat account for the fact that some substances are more easily heated than others; for example, a pint of milk boils more quickly than a pint of water, oils are quickly warmed, and a copper kettle is slightly better than one composed of aluminium. But the greatest practical result is that depending upon the relative capacities for heat of water and land. The sea takes very much longer to warm up in summer than land does, hence at this time of the year the sea keeps the land near it cooler than it would be if it were part of a continental mass. In winter the sea loses its heat slowly and so causes the adjacent land to be warmer than it would be if far removed from the ocean.

For these reasons maritime climates are more equable, that is, less subject to extreme temperatures, than continental climates.

Large tropical masses of land near the ocean are subject to periodic winds called **monsoons** which depend upon the relative amount of heat in water and land. In the hotter season the temperature of the land rises rapidly and the air above it ascends vertically, and cooler rain-bearing winds blow from the sea to

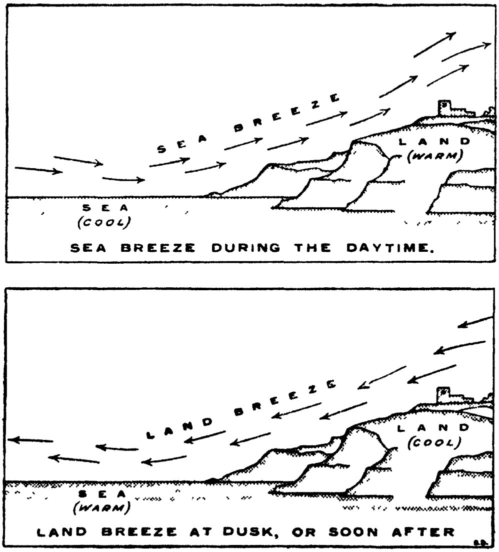


FIG. 167.—LAND AND SEA BREEZES.
THE TERMS WARM AND COOL INDICATE *relative* CONDITIONS.

the land. This continues for some months and then conditions are reversed; the sea being relatively warm, the winds then blow from the land to the sea, and this is the period of smaller rainfall. The northern part of Australia and some other regions are subject to monsoons of this kind. Somewhat similar effects, but on a smaller scale and of daily occurrence, occur at most coastal places and are called land and sea breezes (Fig. 167). During the day the warmer air above the land ascends and the cooler air

blows in from the sea, but at dusk conditions are reversed, and a land breeze sets in.

The south-west monsoon which brings rain to India in the spring is not, however, due to the heated land of India, as is usually stated, but to moist air from the South Indian Ocean being forced upwards when it reaches high mountain walls, and thus cooled by expansion and elevation, with the result that its moisture is precipitated.

The units of heat we have so far considered are calories, which are of scientific importance because they are related to grammes, the units of weight. In physiology **large calories,** each equivalent to 1000 ordinary calories, are employed (see Chapter XI). In connection with heat engineering, the **British Thermal Unit** (B.Th.U.) is employed, this unit being the quantity of heat required to raise the temperature of 1 lb. of water 1° F. Suppose a saucepan holds 5 lb. of water, and it is required to heat this water from 60° F. to 212° F., or the boiling point, how many British thermal units are required?

The units necessary are $5 \times 152 = 760$, if we ignore the heat taken by the saucepan. If we include this, and the saucepan weighs another 5 lb., then, since the specific heat of iron is 0·114, the extra B.Th. units required are $5 \times 0{\cdot}114 \times 152 = 86{\cdot}64$, making a total of 848·64.

Since coal gas is now used mainly for heating, its quality depends upon how much heat it produces per cubic foot. The unit employed in connection with gas supply is called a **therm** and is equal to 100,000 B.Th.U. If the gas is of the proper quality, 222 cubic feet of it will, in burning, yield one therm. Though the quality is determined by the fraction of a therm per cubic foot, the consumer is charged for the number of cubic feet consumed.

CHAPTER XIX

THE RELATION BETWEEN HEAT AND WORK

WHEN the temperature of a bar of iron is raised its molecules require more room for increased vibration, and the energy necessary for such increased motion and consequent expansion is supplied in the form of heat In causing the expansion of the metal bar heat performs work. The matter can be considered in the converse way; forms of mechanical or other work may be performed with the production of heat; and it was by approaching the problem along these lines that **J. P. Joule** in the year 1849 determined the relation between the amount of work performed and the quantity of heat produced. A definite amount of work is always equivalent to a certain quantity of heat. Dr. Joule was a Manchester brewer by profession and has given us a fine example of successful scientific achievement attained by a business man in his spare time. In his experiments, the actual form of work employed by Joule was that performed by falling weights, the amount of mechanical work being calculated by the size of the weights and the distances through which they fell.

As explained in Chapter XIV, the amount of work is expressed in foot-pounds. In Joule's experiment the energy of the falling weights was communicated by means of wheels and cords to a spindle which rotated as the weights fell (Fig. 168). Attached to this spindle was a set of vanes rotating in water contained in a closed vessel. Joule performed a large number of experiments, and in some cases used mercury in a suitable form of apparatus, but the results always worked out the same. He showed that *in order to raise the temperature of* 1 *lb. of water* 1° *Fahrenheit,* 772 *foot-pounds of mechanical work had to be done.* In more recent times the experiment has been performed with better

apparatus and the result gives 778 foot-pounds as equivalent to the amount of heat required to raise a pound of water 1° F. (one British thermal unit). The relation: 778 foot-pounds of work = one water-pound-degree Fahrenheit is known as **Joule's equivalent**, and is represented by the symbol **J.**

Of course equivalent results are obtained when other units of weight and temperature are employed. In scientific work, **C.G.S.** (centimetre, gramme, second) units are often used, and in this case Joule's equivalent gives the work done by 427 gramme metres per water-gramme-degree Centigrade. Whether the amount of heat developed is expressed in British thermal

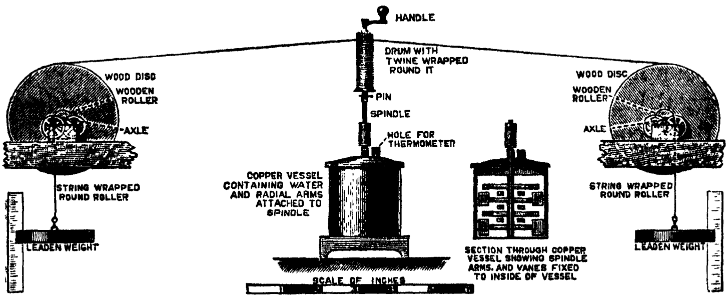


FIG. 168.—THE APPARATUS USED BY JOULE TO DETERMINE THE MECHANICAL EQUIVALENT OF HEAT.

units or calories, the actual relation between work done and heat produced remains the same. The great value of Joule's work lies in its proving that heat is a form of energy and not a kind of material substance as was generally believed prior to 1840, when it was thought that an object was hot because it contained a substance called *caloric*.

STEAM ENGINES AND TURBINES

Heat applied to water does work in raising the temperature, in converting water to steam, and in maintaining the steam at a high temperature and pressure. Because work has been done, the steam in its turn can be made to do useful work by means of its pressure when confined in a closed container.

Steam engines are either stationary and used for driving other kinds of machinery or they are locomotives employed for pulling trains, furniture vans, etc. Locomotives used on roadways are generally termed traction engines.

Everyone is familiar with the chief parts of a steam engine. There is a boiler for the generation of steam which moves a piston in a cylinder, and the movements of the piston cause a wheel to rotate.

The mode of working of a typical stationary engine can be understood by reference to the accompanying illustration (Fig. 169). The **piston** in a cylinder is pushed forwards and backwards by steam,

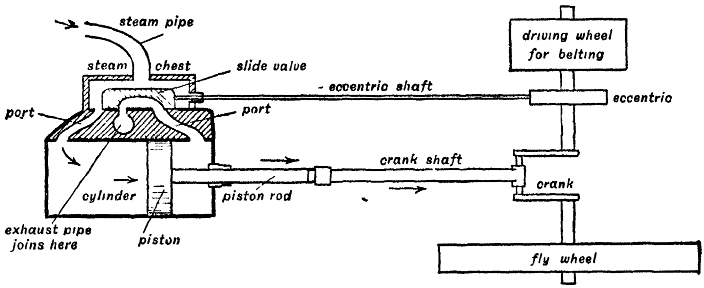


FIG. 169.—PLAN SHOWING THE CHIEF PARTS OF A STEAM ENGINE EMPLOYED FOR DRIVING MACHINERY IN FACTORIES, ETC.

and its movements are communicated to the driving wheel by means of a **piston rod, crank shaft,** and **crank.** A large **fly-wheel** keeps the motion steady. Admission of steam to the cylinder takes place through a steam chest having two separate openings or **ports,** one at the back of the cylinder, the other at the front. A sliding mechanism known as a **slide valve** covers the ports alternately, so that the steam is admitted to the back of the cylinder and pushes the piston forwards and then to the front of the cylinder and pushes the piston backwards. The slide valve itself is operated by a separate shaft and a ring which slides round an **eccentric disc** placed on the shaft of the driving wheel. The eccentric and the ring together form a timing device.

As the piston moves forwards, steam remaining in the front part of the cylinder is discharged through an **exhaust** pipe;

similarly, as the piston moves backwards steam in the back portion of the cylinder escapes through the exhaust pipe. In order that the cylinder shall be as steam-tight as possible, the piston rod passes through an aperture fitted with an arrangement called a **gland** and **stuffing-box,** the stuffing being composed of asbestos.

In a locomotive the parts and mode of working are similar, but there are two pistons, one on either side, and these are connected by crank shafts to the large driving wheels. The more bulky portion of the locomotive consists of the boiler having a large fire box at the rear end and a smoke box at the front end.

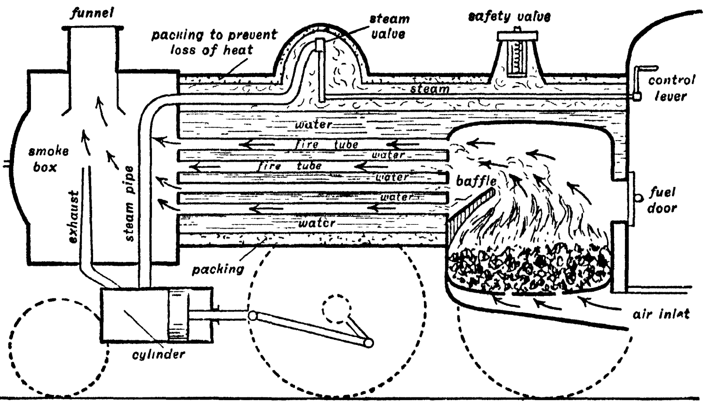


FIG. 170.—VERTICAL SECTION THROUGH THE BOILER OF A LOCOMOTIVE.

The boiler itself is of the ‘ fire tube ’ kind, composed of a large number of tubes along which pass the heated gases from furnaces, and the water is in contact with these tubes (Fig. 170). The heated gases are passed into the smoke box and discharged through the chimney. The puffing of a locomotive is due to steam passed from the exhaust into the chimney, and this causes a strong draught of air to pass from the furnace through the tubes. Pipes communicating with a large steam dome above the boiler deliver steam to the cylinders, and a safety valve prevents the pressure from becoming too great.

The modern steam engine is the result of many successive developments and experiments. Prior to the time of **James**

Watt, such steam engines as existed were employed for pumping water from mines, and were appliances in which condensing steam formed a vacuum so that the air pressure did the actual work. Hence the first of these, known as **Savery's pumping**

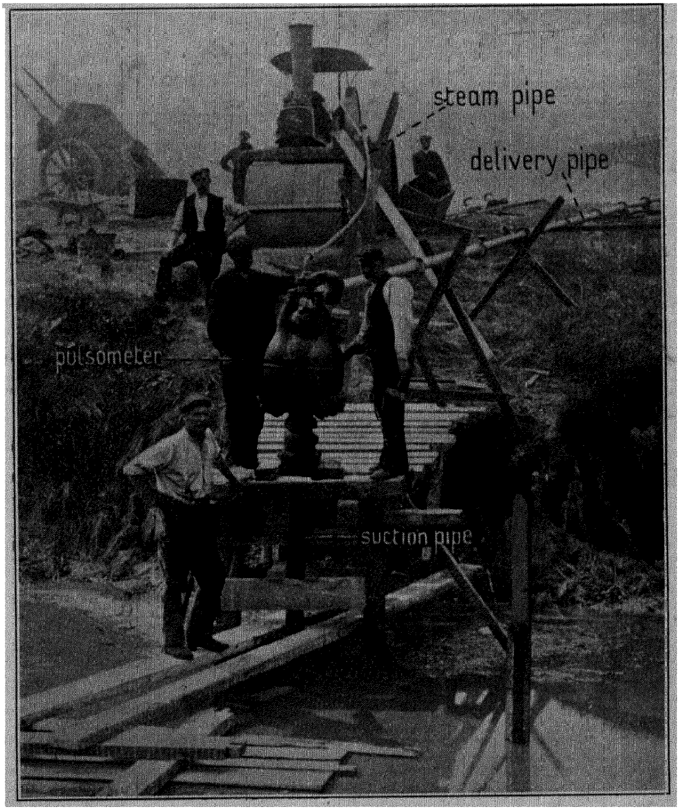


FIG. 171.—A PULSOMETER
USED FOR PUMPING DIRTY WATER FROM OLD CLAY PITS, ETC.

engine, and a later type invented by **Newcomen**, were atmospheric engines. A modern steam pump which may be regarded as a type based upon the principle of Savery's machine is the **pulsometer** (Fig. 171). Watt's earlier engine (1769) used steam in place

of the atmosphere to work a piston, and later, in 1782, he invented the first engine in which steam pressure acted upon both sides of the piston. The engines designed by Watt worked at pressures little more than that of the atmosphere, **Trevethick,** a Cornishman, being the first to use high pressure steam at the beginning of the nineteenth century.

Trevethick invented the first locomotive, which ran on a railway at Merthyr Tydfil in South Wales in 1802, but it was not until 1829, when the **Stephensons** constructed the *Rocket*, that the

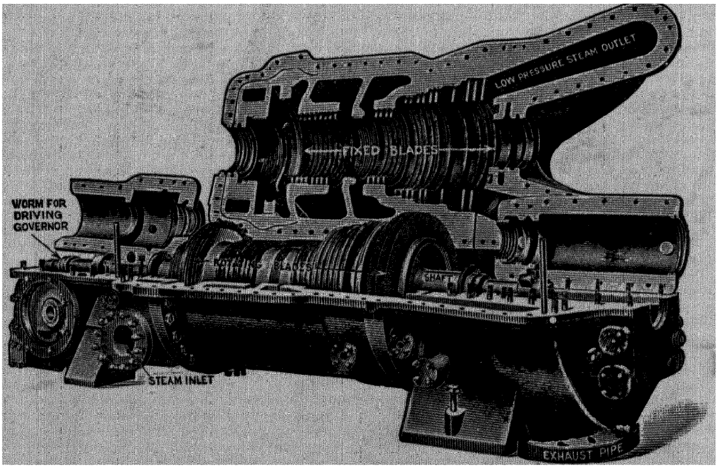


FIG. 172.—A PARSONS' STEAM TURBINE.
THE UPPER PART OF THE CASING LIFTED TO SHOW THE ARRANGEMENT OF ROTATING AND FIXED BLADES.

future of steam railways became assured. The first steamboat, driven by a paddle at the stern, was invented by **William Symington** in 1802, but in 1812 **Bell** constructed the *Comet*, having paddles at the sides.

The most important development in the use of steam power in modern times is the use of the steam turbine, in which high-pressure steam is forced against the curved blades forming an enclosed wheel, or rather sets of wheels.

In the **de Laval** type of turbine steam is directed by nozzles against the blades, and the impact pushes them forward at very

great speed. Such speed is inconveniently great, hence in some forms of steam turbine the rate is reduced by means of gearing. The widely used type of machine invented by **Sir Charles Parsons** makes use of a different principle, the steam *reacting* with curved blades so that they rotate in the other direction, resembling, in this respect, the backward rotation of a lawn sprinkler. Rings of rotating blades alternate with blades fixed to an outer casing, and a distinctive feature is the gradual increase of size of the rings proceeding from the end where the steam enters. This arrangement distributes the fall of steam pressure in such a way that the speed of the shaft is not too great though the power is there all the same.

INTERNAL COMBUSTION ENGINES

In steam engines the energy is derived from combustion of fuel taking place outside of the cylinder, but in petrol engines used for motor cycles, cars, and boats, and in gas engines commonly employed in factories, the combustion of the gaseous fuel takes place within the cylinder itself, hence such machines are operated by *internal combustion*. In all these cases an explosive mixture of air and gas is formed at the head of the cylinder and then fired by electrical or other means just as the piston is starting on a forward stroke. As in steam engines, the energy is the result of chemical work and heat. Since petrol, or spirit obtained from the distillation of petroleum, is so widely used as fuel, the engine of a motor cycle may be taken as an illustration of the way in which internal combustion engines work (Fig. 173).

As in most other engines, a piston moves in a cylinder, and these movements are communicated to a wheel by means of a crank and crank shaft.

Petrol spray is mixed with air and the mixture exploded in a combustion space or chamber above the cylinder. The explosion is brought about by means of an electric spark which passes between two metallic points on a **sparking plug** inserted in the chamber. The entry of the mixture into the combustion chamber is controlled by an inlet **mushroom valve,** so called on account

of its shape, and another similar exhaust valve controls the exit of fired gas from the cylinder. Each valve is kept in place by a spring, except when a rotating **cam** lifts it for the entry of mixture or exit of burnt gas as the case may be.

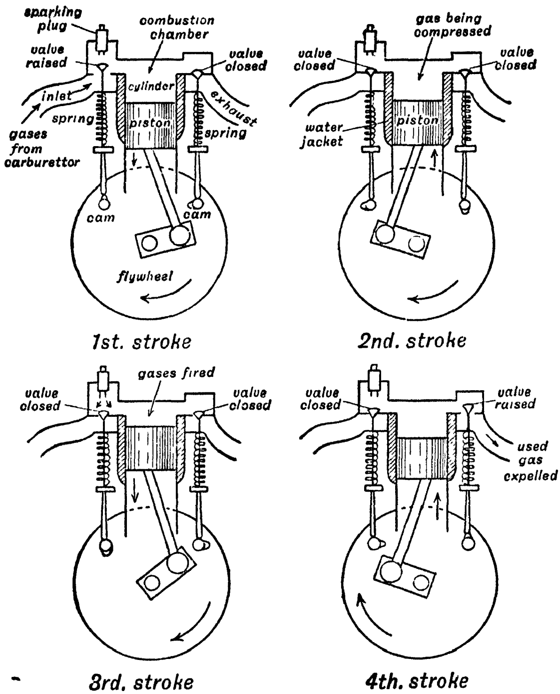


FIG. 173.—THE FOUR-STROKE OR OTTO CYCLE OF THE MOTOR ENGINE.

The machine is called a four-stroke engine because the mixture is actually fired only once in four motions of the piston, two forwards and two backwards.

The cycle of events which occur are as follows :

1st stroke. The piston moves forwards, the inlet valve is raised and the mixture is drawn into the cylinder.

2nd stroke. The piston moves backwards, the mixture is compressed, both valves remain closed.

3rd stroke. The mixture is fired and the piston is pushed forwards, both valves still closed.

4th stroke. The piston moves backwards, the exhaust valve is raised and the burnt gas leaves the cylinder.

The cycle of events is then repeated.

There are other petrol engines in which the necessary events are accomplished in two strokes, but such are only suitable for small motor cycles, their application to motor cars achieving only a limited success.

Apart from the cylinder and piston two other vital parts of a petrol engine are the **carburettor** and the **magneto,** the former delivering a mixture of air and petrol spray to the cylinder, the latter causing an electric spark to fire the mixture of gases just at the correct moment. The mode of working of a magneto is described in Chapter XXVII.

In an aeroplane engine there are several cylinders, arranged radially around the propeller shaft, which is rotated by the properly timed pistons working in conjunction with one another.

A **gas engine** employing coal gas and air works in a manner very similar to that of a petrol engine (Fig. 174). The same

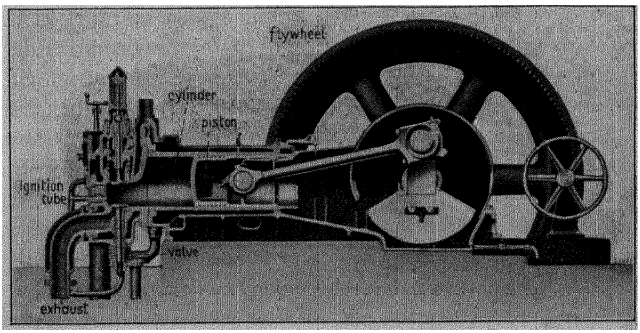


FIG. 174.—A GAS ENGINE AS USED IN FACTORIES.

four-stroke cycle occurs, and valves operated by cams and springs regulate the inlets of gas and exhaust. The ignition or firing of the mixture is effected by means of a red-hot porcelain tube, which is allowed to come into contact with the gaseous mixture at properly

timed intervals by the opening of an adjoining passage. The engine is cooled by water circulating through a space between the cylinder and an outer jacket or covering. **Dr. Otto,** who invented the first satisfactory gas engine in 1876, must be credited with having laid the foundation of the modern internal combustion engine. The sequence of events taking place in the usual four strokes is generally known as the **Otto cycle.**

In **oil engines** an explosive mixture of air and oil spray is used, such mixture being fired by the hot walls of the vaporiser itself. As before there is a four-stroke cycle, but this is modified in a special type of machine called the **Diesel oil engine.** In this, air only is admitted to the cylinder at the first stroke; during the second stroke this air is strongly compressed, so that the temperature is raised to about 1000° F. At the commencement of the third stroke oil is sprayed into the cylinder and the mixture exploded by its own high temperature. As usual, the last or fourth stroke forces the burnt gas out of the cylinder. The Diesel engine has a higher efficiency and greater economy than that of any other kind of heat engine. It is now being used on ships, many large liners being operated by oil and known as motor ships.

A new type of machine called a **Still engine** employs both oil and steam as sources of energy. The oil is fired inside the cylinder as in the Diesel engine, the steam being used at the correct moment on the other side of the piston to push it back.

With regard to heat engines in general, it must be observed that in all of them only a relatively small part of the heat produced is converted to a suitable form of mechanical energy. At the bottom of the scale is the ordinary steam locomotive, which converts only 5 per cent. of the heat to useful energy, and at the upper end of the scale is the Diesel engine, having an efficiency approaching 40 per cent. A marine steam turbine is nearly, but not quite, as efficient in this respect as a Diesel engine.

CHAPTER XX

THE TRANSMISSION OF HEAT

WHEN possible, heat will pass from a substance of a higher temperature to another at a lower temperature. If no means of escape presents itself, then the heat must stay where it is, but such cases are relatively rare. An apparatus which almost completely prevents the escape of heat is a **vacuum flask,** which consists of an inner vessel nearly surrounded by another outside vessel, the space between the two being nearly a vacuum (Fig. 175). Any hot liquid placed in the inner vessel retains its heat for many hours because the vacuum permits only a very slow escape. The small quantity of heat which does pass proceeds by radiation, but even this is minimised by a reflecting surface of mercury on the inner surface of the larger containing vessel. A very cold substance such as liquid air can also be kept in such a flask, since heat is similarly prevented from passing inwards. The chief function of clothing, particularly in winter, is the retention of the heat in our bodies, but clothing does not do this so efficiently as a vacuum flask for reasons mentioned later.

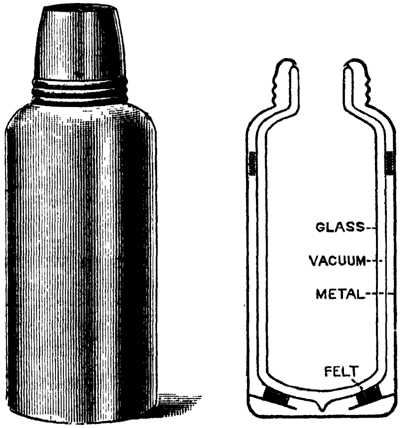


FIG. 175.—A THERMOS FLASK.

When a hotter substance is in contact with, or near, cooler objects, the heat, or at any rate part of it, generally finds some means of passing to the cooler substances. This transference of heat may take place in one or more of three ways, sometimes in all three ways operating together, according to the circumstances.

Consider the case of a kettle containing water placed over an ordinary gas burner. The heat supplied by the burning gas warms the outer surface of the metallic substance composing the kettle. Each particle of metal *by contact* passes heat to the particle next to it, and very quickly the inner surface of the

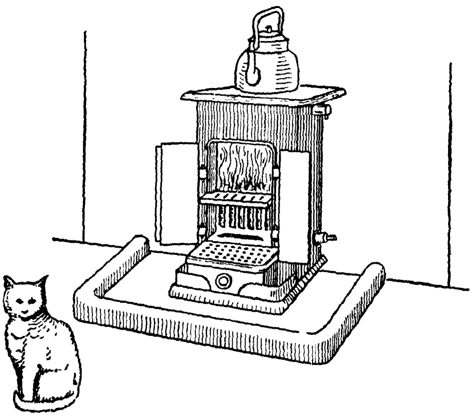


FIG. 176.—THE WAYS IN WHICH HEAT IS TRANSMITTED.
THE KETTLE RECEIVES HEAT FROM THE FIRE BY CONDUCTION, THE WATER IN IT IS HEATED BY CONVECTION, WHILE THE CAT RECEIVES HEAT BY RADIATION.

kettle is heated strongly. When heat is transmitted through a solid body in this way the process is known as **conduction.** The water near the bottom of the kettle becomes heated, but in this case, the heated particles being less dense than the cooler particles above, they rise through the water and take their heat with them. In this way a current or circulation of heated particles is produced, and heat transferred from one place to another in this way is said to be transmitted by **convection.** It is obvious that such convection currents occur only in fluids. Unlike solids, liquids and gases are warmed by convection, not by conduction. Now, all of the heat emitted by the burning gas is not obtained by the

kettle and water; some of it gives rise to convection currents in the air, but some also passes through the space around the kettle by a process termed **radiation.** If the burning gas is turned off, and a few minutes later a hand is placed an inch or two in front of the kettle, the hand experiences the sensation of warmth because it receives radiant heat which is being radiated in all directions through the space around the kettle. This is not a case of convection, and the *air itself is not appreciably warmed by the radiant heat which passes through it.*

This important fact should be remembered as it explains many things in connection with the atmosphere and climate. Though the air around him may be cold, a person standing in the sunshine at the top of a mountain may be uncomfortably warm. The sun warms *him*, but not the air around him. Heat from the sun reaches the earth after traversing about 93,000,000 miles of space in which there is no ordinary matter. Radiant heat is a kind of wave-motion proceeding through the ether which occupies all space, heat waves being closely related to light waves, as described in Chapter XXII, which deals with light and colour.

CLOTHING AND DOMESTIC HEATING

We must now consider examples of practical consequences arising from the three modes of heat transference—conduction, convection, and radiation.

Solid substances which permit heat to pass easily or rapidly through them are said to be good conductors; others which do not permit such easy passage of heat are bad conductors. Most good conductors are metals or metallic alloys, and for this reason such substances as copper, iron, brass, and aluminium are employed extensively in kettles, saucepans, preserving pans, and many other domestic appliances. Because these substances easily conduct heat, they feel cold when in contact with our bodies; heat is rapidly withdrawn from us, and its loss produces the sensation of 'coldness.' Sea or tap water also feels cold, because convection currents occurring in it quickly take heat from the body.

On the other hand, wood and fabrics made of wool, cotton, or silk, are classed as bad conductors ; they do not feel cold because they do not conduct heat away sufficiently well for us to experience a distinct drop in bodily temperature. The temperature of the body must be maintained, and this is done partly by taking sufficient quantities of heat-producing foods, such as the carbohydrates sugar and fat, partly by exercise, and partly by the use of suitable non-conducting articles of clothing. Silk, wool, and to a lesser extent cotton, make clothes which are fairly efficient as far as non-conducting properties are concerned. A slow loss of heat takes place, however, since small convection currents are set up in the air occupying the minute spaces or pores in the material (Fig. 177). Leather, which is relatively non-porous, is worn by aviators and motorists.

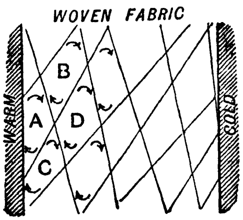


FIG. 177.—CONVECTION CURRENTS IN AIR CAVITIES OF FABRICS.

THE FIBRES BETWEEN THE CAVITIES (*A*, *B*, *C* AND *D*) BECOME WARMED BY THE AIR AND PASS HEAT TO ADJOINING CAVITIES.

The relation between clothing and radiant heat must not be overlooked. Black or dark coloured clothes generally absorb more radiant heat than white or light coloured clothes, hence the use in summer of white straw hats, and light coloured flannels, which act not only as poor conductors, preventing the penetration of the sun's heat, but as reflectors as well. Rays of heat can be sent back or **reflected** just as light rays are, and the reflecting properties of a hat are increased if it has a shiny surface ; even a black silk hat being cooler than one composed of dull black felt. Similarly, well polished black shoes may be cooler than others made of dull light-coloured suede.

The primary reason for all domestic and public heating is the maintenance of the correct bodily temperature, and it may be as well to consider the usual methods by which the required result is obtained. An ordinary coal fire warms our rooms and our persons partly by radiation and partly by convection. Only the actual fireplace itself and objects such as a poker placed in the fire are heated by conduction. The air in the room is warmed by convection currents, which also deliver heat to objects including

ourselves placed at various positions in the room. Heat is also taken to various parts of the room by radiation, and this mode of transmission is more perceptible if we deliberately stand in front of the fire. The use of a fire screen prevents transmission by radiation, and if a glass screen which is transparent to light but absorbs heat rays is used, we can enjoy the appearance of the fire without experiencing too much warmth.

In the older type of grate much heat escaped as convection currents in gases passing up the chimney, but more modern types of fireplaces seek to minimise this loss by having the back part inclined forwards, thus directing the heat forwards rather than upwards. Electric fires are provided with polished curved reflectors placed at the back so that radiant heat is reflected forwards (Fig. 247).

In the system known as **central heating**, common in hotels, schools, large houses, etc., hot water circulates through a series of pipes, and the process is one of convection combined with radiation (Fig. 178). Water is heated by a boiler in the basement, and the convection currents cause heat to be taken to the top of the building and the heated water circulates through various **radiators** in rooms on different floors. The great advantage of this mode of heating is the even distribution of temperature obtained. A person does not go from a hot sitting room to a much colder bedroom, and the rooms are kept at a fairly constant temperature day and night.

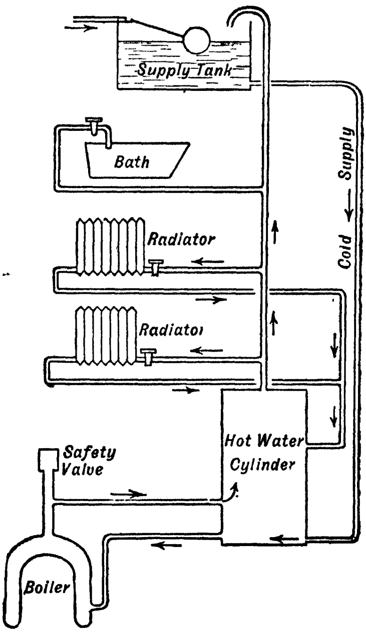


FIG. 178.—DIAGRAM SHOWING THE ARRANGEMENT OF PIPES, ETC., IN CENTRAL HEATING.
CONVECTION CURRENT INDICATED BY ARROWS.

Though smaller residences do not possess central heating, practically all houses of recent construction are supplied with a hot-water system which, operating in a similar way by convection, yields a constant supply of hot water for the bathroom and kitchen. The upkeep is quite economical, since any modern slow combustion stove placed in the kitchen or scullery consumes cheap fuel, such as coke mixed with household refuse. In winter these domestic boilers help to keep the water in other pipes from freezing, but where pipes extend along relatively exposed positions, such as in a loft or cellar, they should be covered by such non-conducting materials as felt or sacking. Loss of heat from the water in the pipes is thus lessened, and a 'burst' caused by the expansion which takes place when water changes to ice is not so likely to occur.

Compartments in trains are warmed by steam forced along pipes in and below the carriages.

Before we consider other important cases of convection and radiation, some practical applications of conduction must be noted. Metal teapots should be fitted with wooden handles or have handles effectively protected from the heat by porcelain or other poorly conducting substances. The relatively non-conducting nature of porcelain and china ware is illustrated by the fact that no special handles are necessary in the case of china teapots, cups, and jugs. Most rocks are bad conductors of heat, so that slabs of fine grained sandstone, ganister, dolomite, and others are used for the linings of furnaces. So called 'fire' clays produce the brick-like material generally forming the back, sides, and base of a modern fireplace. These substances are not only bad conductors, but also withstand a very high temperature without undergoing chemical alteration.

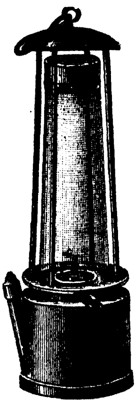


FIG. 179.—A MINER'S SAFETY LAMP.

A particularly interesting and useful case of rapid conduction by metal is afforded by the **miners' safety lamp** (Fig. 179). Copper gauze, if pressed down upon the flame of a gas burner, does not allow the flame to pass through it, although the gas itself proceeds through the meshes of the

gauze. So effectively is the heat conducted away from the spot that the temperature of the gas is lowered below the *ignition point* as it passes through the gauze, and only when the heated metal becomes red hot will the gas above it ignite. In the miners' safety lamp, invented by **Sir Humphry Davy,** the flame of the lamp is surrounded by glass, but above this is a space bounded all round by fine copper gauze. Inflammable gases which may be present in a pit can pass through and burn inside the lamp, but the flame cannot get through to the outside and so fire an explosive mixture of gases.

VENTILATION AND WINDS

The fluid nature of air permits expanded warm particles to rise and cooler denser particles to sink. When warmer air rises, cooler air flows in to take its place, and a general convection current or circulation is produced. This occurs on a small scale in any well ventilated room (Fig. 180), and on a very large scale over those enormous expanses of the earth's surface where the chief permanent winds circulate (Fig. 181).

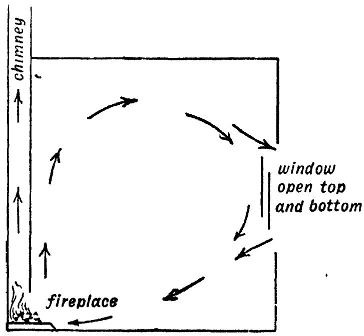


FIG. 180.—A ROOM VENTILATED BY CONVECTION CURRENTS CAUSED BY A FIRE.

In a room the exhaled breath from people's lungs is slightly warmer and less dense than the rest of the air, consequently such bad air rises to the upper part of the room. For this reason adjustable ventilators or small windows should be placed fairly high up in the wall, and as the bad air escapes through these, fresh air enters by any of the openings lower down, such as the space between the door and the floor. This often means an unpleasant draught, hence it is better to admit fresh air by an opening in the wall half-way towards the ceiling. An ordinary coal fire affords one of the best means of ventilation, since it

causes a strong up-draught in the chimney, but even then there should be some ventilator or opening placed near the top of the room. In former times mines were ventilated by placing a fire at the bottom of one shaft, fresh air being forced down another shaft to take the place of that ascending above the fire, but at the present time powerful fans operated by steam or electricity at the pit-head produce the necessary current of air through the workings of the mine.

Enormous convection currents circulating along definite routes above the earth's surface are known as **permanent winds** since they continue without interruption, for the simple reason that the conditions which produce them are permanent (Fig. 181). The most typical of such air currents blow across land and sea within the tropics and are called **trade winds** because of their very beneficial aid to shipping, particularly in the days when sailing vessels were the only kind crossing the ocean. Air obtains its heat, and consequently its temperature, from the land, sea, and other objects with which it comes in contact. The sun's rays warm the land and water, and these warm the air touching them. Along a broad belt extending a few degrees of latitude each side of the equator the air thus becomes heated and rises vertically. A person in this belt experiences no *horizontal* motion of air commonly called a wind, and the belt is known as the region of **equatorial calms**, often called the doldrums. The cooler air a few degrees farther north and south flows steadily in towards the equator to take the place of the ascending equatorial air. These inflowing trade winds would blow directly from the north and from the south if the earth did not rotate, but this motion of the earth causes the trade winds to flow from the north-east and south-west respectively. Winds are named according to the direction from which they blow. These particular winds carry enormous quantities of water vapour obtained from the ocean which eventually produces the heavy rainfall in countries lying in their track, for example, Brazil in South America.

What happens to the heated equatorial air after it has ascended some distance in the atmosphere? Some of it proceeds towards the north-east and some towards the south-east, and eventually it descends again at the polar regions where there are **polar calms**,

the air movement being vertical, not horizontal. Some of this air descends a little north of the Tropic of Cancer and some a little south of the Tropic of Capricorn, hence there are two other belts of calms, one near either tropic. North and south beyond the tropics, in more temperate latitudes, other convection currents produce the permanent **westerly winds,** which include those

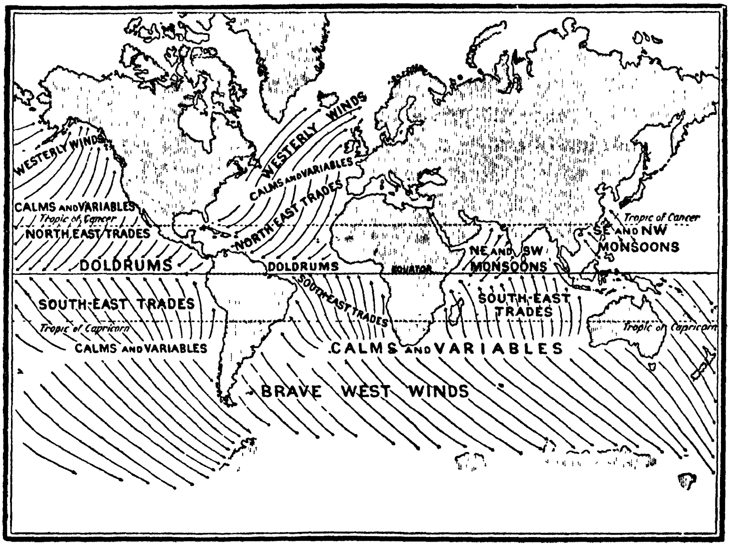


FIG. 181.—THE PERMANENT WINDS OF THE WORLD.

mainly responsible for the climate of the British Isles and north-west Europe. These westerly winds are more stable in the southern hemisphere owing to the greater extent of ocean there, the more diverse mixture of land and sea in the northern hemisphere having a tendency to modify these winds. The strong westerly winds of the south are called the **roaring forties,** since they occur in latitudes roughly 40° south. In southern Asia, where diversity of land and sea again modifies winds, convection currents result in the monsoon changes mentioned in the previous chapter, where land and sea breezes were also described, since such cases are brought about largely by specific heat as well as

convection. Of course, the whole convection wind system moves slightly northwards and southwards according to the position of the sun at different times of the year.

RADIATION AND THE THERMOPILE

Life is possible on the earth because of the heat received from the sun, and all of this heat reaches us by radiation. We owe our very existence to waves of radiant heat. If the earth were a flat table at right angles to the sun's rays, all parts of it would receive the same amount of heat per square mile, but since the earth is not flat but curved, the amount of heat received per square mile varies with latitude and with the season. The sun's rays strike more obliquely in higher latitudes than they do near the equator, and the effect of this has been discussed in Chapter II, where features resulting from the earth's shape were described.

Since the sun's rays do not appreciably warm the air, a thermometer placed in direct sunshine measures the temperature of itself heated by the sun, not the temperature of the air. For this reason all thermometers used in connection with meteorological reports concerning air conditions are placed in a Stevenson's screen. If it is desired to measure the solar radiation, or heat of the sun's rays, a special radiation thermometer having a dull blackened bulb is employed. Such a thermometer reflects very little of the radiant heat, and quite often it registers a temperature of 120° F. or more. If the air received its heat directly from the sun's rays, summer conditions would be unbearable.

In reality, an extremely small fraction of the sun's total heat is received by the earth, for two reasons—relatively a few only of the rays strike the earth, and the amount of energy received from such rays is less the greater the distance an object is placed from the source of heat. We are at an enormous distance from the sun. It can be proved experimentally that the amount of energy received varies inversely with the square of the distance. This is another case of the inverse square law so often met with in natural phenomena.

This important rule and many other interesting facts concerning radiant heat can be verified by means of an apparatus

called a **thermopile** (Fig. 182). This consists of a number of metallic couples each composed of a small bar of antimony joined at one end to a similar bar of bismuth. Such a couple has the property of producing an electric current when the junction of the two metals is heated while the remote ends are connected by a wire. This is an example of the conversion of heat energy into that of electricity. The effect can be increased by having a large number of such couples joined together in series or one after another, and the effect can be rendered visible if the electric current produced is passed through a sensitive galvanometer. The thermopile has several of these couples, and one side of the arrangement is

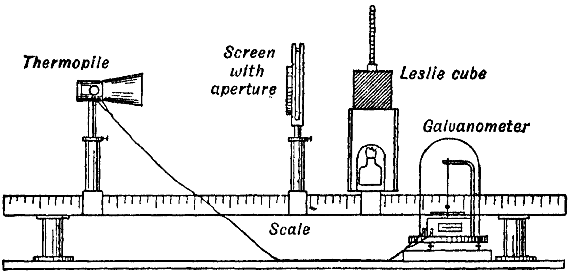


FIG. 182.—APPARATUS FOR THE STUDY OF RADIANT HEAT.

fitted with a conical funnel which concentrates heat rays upon the ends of the metallic couples.

In experiments on radiant heat, a **Leslie cube** or hollow metal cube containing hot water supplies the heat waves. The thermopile is placed at a definite distance from the cube, and the deflection of the galvanometer needle is noted. Then with the water at the same temperature the thermopile is placed at twice the distance and the movement of the galvanometer noted again. It is found that at twice the distance only $\frac{1}{4}$ of the effect is produced, the radiant heat captured being only $\frac{1}{4}$ of that received before. At three times the distance only $\frac{1}{9}$ of the heat is received, though the hot water remains at the same temperature. Hence the law of inverse squares.

The Leslie cube has four vertical faces, two white and two black. One of the white faces is polished, the other dull; similarly with the black faces. Now though all of the faces must be

at the same temperature it is found that they do not all radiate heat equally well. The dull black surface radiates heat better than the others; the white polished face gives the smallest result. From this it follows that radiators used in the central heating of buildings operate best when they are dull black, and a silver teapot retains its heat longer when kept well polished. In general, it is found that good radiators also absorb heat well, and *vice versa*.

A thermopile can be used in experiments on **diathermancy,** or the transparency of various substances to heat rays. A piece of glass placed between the thermopile and the Leslie cube allows light to pass through but stops most of the heat rays, as shown by the effect on the galvanometer. On the other hand, a slab of rock salt of the same thickness permits nearly all the heat rays to pass through it, though it is almost opaque to light. Dry air is very diathermanous, but water vapour in air stops the passage of a large proportion of the heat rays. A clear starlit night is colder than a cloudy one at the same time of the year, because clouds and mists prevent excessive radiation of heat from the earth. But it must be remembered that the temperature of the source of heat is a factor in diathermancy. A large proportion of heat rays from the sun can pass through the glass of a greenhouse, but heat radiated at night by objects in the greenhouse cannot escape, hence the temperature is properly maintained.

CHAPTER XXI

HEAT AND CHANGE OF PHYSICAL STATE

THE substance we call water also exists in the solid form called ice, and in the gaseous form called steam. All three forms are identical in chemical composition, though each has different physical properties; for example, water is the heaviest of the three, steam is the lightest, bulk for bulk. The physical state, whether solid, liquid, or gaseous of this substance, is determined by the temperature and the pressure upon it. Thus at ordinary atmospheric pressure and at temperatures below 0° Centigrade the substance is solid ice, between 0° C. and 100° C. it is liquid water, and above 100° C. it is gaseous steam. At normal pressure 0° C. is called the melting point of ice, and 100° C. is known as the boiling point of water. An alteration in the pressure slightly alters the melting and boiling points. An increase of pressure lowers the melting point of ice but raises the boiling point of water as we shall see later. An iron weight suspended by a wire over a block of ice slowly pulls the wire through it, since its pressure added to that of the atmosphere causes the ice immediately below the wire to become liquid (Fig. 183). The new water thus formed emerges from beneath the wire and immediately re-freezes.

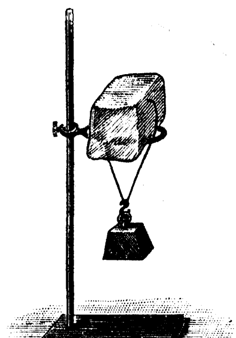


FIG. 183.—AN EXPERIMENT TO ILLUSTRATE REGELATION.

This process of re-freezing is known by its French name of **regelation.** The ice of a glacier pressed against the sides of its valley

melts, and in this way the glacier adapts itself to the shape of the valley. The conversion of snow in a mountain snowfield to glacier ice is another example of regelation; the lower pressed snow melts, emerges from the mass, and then immediately re-freezes, forming a glacier. When snow is just about 0° C. in temperature a little pressure of the hand suffices to melt it and then on relaxing

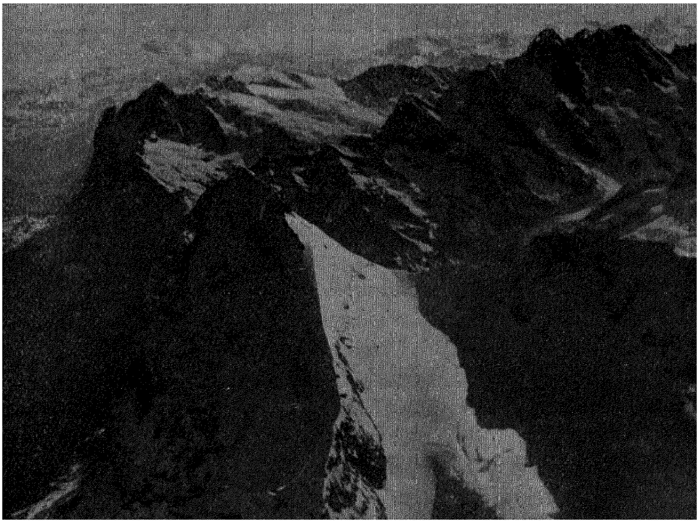


FIG. 184.—AN ALPINE SNOWFIELD.
SOME PEAKS AND CRESTS OF THE BERNESE OBERLAND.
(*Aerial photograph by Lieutenant Mittelholzer.*)
(By courtesy of the Swiss Federal Railways.)

the pressure it re-freezes forming a snowball. On a very cold winter's day when the temperature is some degrees below 0° it is not easy to make a snowball, more pressure being necessary. Snow itself consists of a loose mass of beautifully shaped aggregates of ice crystals.

Ice is lighter than water, and this means that when water changes to ice an increase of volume takes place. This is of considerable practical importance. The expansion accompanying

the formation of ice in water pipes exerts great pressure and may burst a pipe at a weak spot, and then, when a thaw comes and the ice melts, a bad leak is found. Icebergs, being slightly lighter than an equivalent volume of water, float with only a small fraction of their bulk above the sea-level, thus becoming a source of danger to shipping (Fig. 142). When water in a pond freezes the ice collects at the top, leaving warmer denser water below. In the case of snow, air being present as well as ice, the volume is even greater, and in meteorological work, snowfall is estimated as rain by allowing the snow to melt before it is measured. A fairly deep fall of snow may be equivalent to less than an inch of rain.

HEAT ABSORBED BY MELTING ICE

In connection with the melting of ice there are some quantitative relations which must be considered carefully. If some *dry* ice is placed in a vessel and gently warmed the ice slowly melts. A thermometer placed in the water being formed shows that its temperature remains at 0° C. so long as any ice remains unmelted. Only after all the ice has been changed to water does the temperature begin to rise. Yet heat has been steadily supplied the whole time. What has happened to this heat? It is obvious that a certain quantity of heat has been used up in the process of converting ice to water. Heat absorbed in this way is said to be **latent,** since it does not make itself apparent by a rise in temperature. It requires energy to change a solid to a liquid, and this energy is supplied in the form of latent heat. The number of heat units required to convert one gram of ice to water, without changing the temperature, is a quantity known as the **latent heat of fusion of ice.**

This quantity can be found quite easily by putting some dry ice into a calorimeter containing a certain quantity of water (Fig. 185). Heat passes from the water to the ice, which melts and adds so much new water. While the ice is melting the temperature falls as shown by a thermometer, and by noting the total fall of temperature we can calculate how many heat units have been used to convert the ice to water, provided the weight

of water before and after the experiment is known. If the weight of water were 100 gm. at first and 110 gm. afterwards, it is clear that 10 gm. of ice were placed in the water.

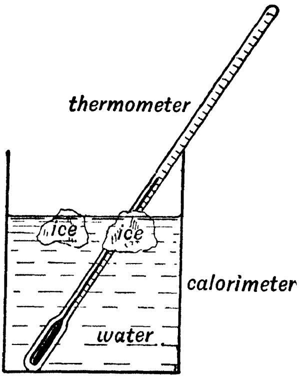


FIG. 185.—APPARATUS FOR THE DETERMINATION OF THE LATENT HEAT OF FUSION OF ICE.

Let us suppose that the temperature of the water was 15° C. before the ice was added, and 6·4° when all the ice had just melted. Now the heat units lost by the water are found by multiplying its original weight by the fall in temperature. In this case we have $100 \times (15 - 6{\cdot}4) = 860$ units which have been absorbed in melting 10 gm. of ice, *and in raising 10 gm. of new water from* 0° *to* 6·4° *C.* Therefore to melt one gram of ice the heat units required are $\frac{860}{10} - 6{\cdot}4$, the rise in temperature of the new gram of water being deducted.

$\frac{860}{10} - 6{\cdot}4$ gives **nearly 80 as the latent heat of ice.**

About 80 calories are required every time one gram of ice at 0° C. is converted to water still at 0° C.

In experiments on latent heat, the copper calorimeter loses or receives so much heat; in cases where ice is used it loses some, and allowance must be made for this. As the specific heat of copper is about 0·1, it is usual to weigh the calorimeter, multiply the weight by 0·1, and call the quantity obtained so much extra water, for heating up the calorimeter itself is equivalent to this quantity of water. Thus in the case given above, suppose the calorimeter weighed 50 gm. and 95 gm. of actual water were placed in it. The 50 gm. of copper are equivalent to another 5 gm. of water, making 100 gm. in all, and in this case the figure '5' is the **water equivalent** of the calorimeter.

Eighty calories per gram is a fairly large quantity and explains why large lumps of ice keep fish and other commodities cool for a long time. These things give their heat to the ice and until

all of it has melted the temperature remains very low. The considerable drop in air temperature which produces fogs in the iceberg region off Newfoundland, etc., is also due to the absorption of latent heat by melting ice. If we desire to keep ice for some time, it must be wrapped in some non-conducting material, such as a blanket, cotton wool, or sawdust, which will prevent heat getting to it.

When other solids melt, latent heat is similarly absorbed in the process, but most substances do not require so much heat per gram as ice does. For example, paraffin wax melts at 52° C. and each gram requires only 35 calories to melt it. In the case of sulphur, a gram requires only 9·4 calories.

In spite of fogs near icebergs, it is fortunate that the latent heat of ice is relatively high, since a low value would mean rapid melting of snow on mountains, causing disastrous floods, and with a fall of temperature ponds and lakes would quickly become completely frozen, with destruction of animal life, and burst pipes in houses would be very common. Latent heat works both ways; water gives out 80 calories per gram when it becomes ice, and if the latent heat were much less ponds would more easily freeze (and melt).

HEAT ABSORBED WHEN WATER BOILS

When any liquid is changed to a gas, energy in the form of heat is used up without a change of temperature taking place. Thus when water at 100° C. becomes steam at the same temperature, the heat absorbed in the conversion of water to steam is latent, and in this case is described as **latent heat of vaporisation.** If some steam is passed into a definite weight of water in a calorimeter (Fig. 186) and the temperatures before and after adding the steam are noted, the actual amount of heat given out by every gram of steam at 100° in becoming water at 100° can be ascertained. If the water is weighed again the extra weight is that due to steam added. Now the heat lost by the steam is equal to that gained by the water *less a small amount supplied by a few grams of new hot water in cooling from* 100° *to the final temperature* of the mixture. An allowance must be made for this as shown

below. Let us suppose that 100 gm. of water at 15° C. were used originally (including the water equivalent of the calorimeter), and that 10 gm. of steam were added causing the final temperature to be 71·5° C. The heat units gained by the water $= 100 \times (71{\cdot}5 - 15) = 5650$, and these were supplied by 10 gm. of steam in becoming water and by 10 gm. of hot water in cooling from 100° to 71·5° C., a quantity which must be deducted. Therefore 10 grams of steam in becoming water yield:

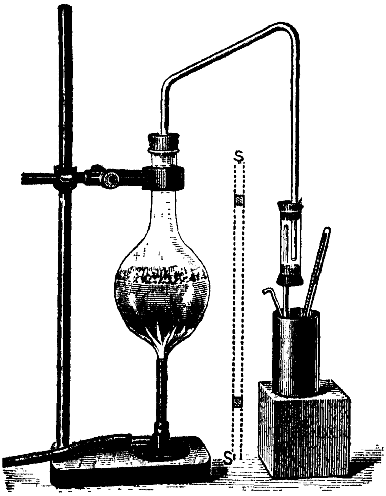


FIG. 186.—APPARATUS FOR THE DETERMINATION OF THE LATENT HEAT OF VAPORISATION OF STEAM.

$$5650 - (100 - 71{\cdot}5) \times 10$$
$$= 5650 - 285 = 5365.$$

Thus every gram of steam yields about 536 calories in becoming water, and conversely it requires about 536 calories to convert every gram of water to steam without a change of temperature. **The quantity 536 is known as the latent heat of steam.** In experiments of this nature it is important to see that no hot water passes in with the steam, hence the use of a suitable trap to catch water formed by condensing steam.

536 is a very big number and explains why so much fuel must be used to convert water to steam in a locomotive or other steam engine. On the other hand, quite a small quantity of steam gives out sufficient heat to warm a railway carriage.

The temperature at which water or other liquids boil depends upon the pressure exerted upon it; in the case of water the boiling point is 100° C. *under normal atmospheric pressure*, which in a barometer is represented by a column of mercury 30 inches in height. At the top of a high mountain water boils at a lower temperature than 100° C. because the pressure of the atmosphere

on the water is reduced. In a deep valley below sea-level, such as that of the Jordan in Palestine, the pressure is greater than normal, hence water boils there at a temperature higher than 100° C. Evidently water boils at a temperature when the pressure of its steam is just in excess of that of the atmosphere pressing upon it. The air pressure and the steam pressure oppose each other, and provided sufficient heat is supplied, the air will eventually lose the contest and the water will boil, its steam will escape.

The influence of pressure on the boiling point of a liquid is very important. Water in a boiler of a steam engine must be heated beyond 100° C. to overcome the pressure of the steam in the boiler itself. Both water and steam in a closed space become superheated and the pressure increases according to Charles's Law as we have seen.

EVAPORATION, CONDENSATION, AND WEATHER

When water is being heated in a kettle, the source of heat is generally placed below the kettle; hence water at the bottom becomes hotter sooner than that at the top, though convection is endeavouring to heat all parts. After a while, bubbles of steam form at the bottom, rise through the water, reach cooler layers above, and are converted to water again. This process is accompanied by a characteristic noise known as *singing*. A little later the water becomes more uniformly heated, the singing becomes less pronounced, and the water boils.

In boiling, all parts of the liquid are concerned, and a definite temperature is necessary, but liquids may become vapour at lower temperatures by a process known as **evaporation,** *which takes place at the surface only*. Thus water exposed to the air evaporates slowly, and since the process occurs only at the surface, the rate of evaporation depends to some extent upon the shape of the containing vessel. A gallon of water will disappear more quickly from a shallow bath than it will from a tall jug, but the rate of evaporation is mainly determined by another important factor, namely, *the condition of the air at the time*. If the air holds as much water vapour as it can do it is said to be

saturated and will take no more. Water exposed to such air will remain as it is; no more will evaporate until the air conditions become unsaturated. A rise in temperature will render the air unsaturated and then evaporation will proceed from the water.

If a fall of temperature occurs in air already saturated, then some of the water vapour, by the process called **condensation,** is thrown out as drops of water, and this explains the formation of rain, snow, mists, fogs, and the deposit of a film of moisture on walls and furniture on certain days when the air happens to be saturated and is slightly cooled. It is important to realise that on a warm summer's day the air holds quite a lot of water vapour, but it may not be saturated because the temperature is high. On such a day a tumbler containing cold water cools the air near it, so that a film of moisture is deposited from this air on the *outside* of the tumbler. The air near the tumbler has been cooled and brought below saturation point. The formation of **dew** is similarly caused by air being cooled below the saturation temperature by the cold ground, and the deposit of dew will be greatest on those objects which radiate heat best, and consequently become cooled quickly. When the air is nearly saturated a slight fall of temperature leads to the deposit of moisture, but when it is far from being saturated a big drop in temperature is necessary. The temperature at which dew or moisture is deposited is called the **dew point,** and it follows from what has just been said that the dew point varies considerably. In winter this temperature may be below o° C., in which case a solid white **frost** is deposited.

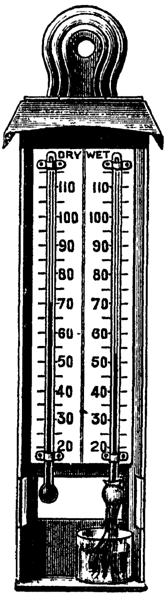


FIG. 187.—WET AND DRY BULB HYGROMETER.

The condition of the air, whether it is saturated or not, can be ascertained by the use of an instrument known as a **hygrometer,** so named because it indicates the amount of moisture in air. A common form of such instrument consists of two thermometers placed side by side, but a slight distance apart

(Fig. 187). One of these thermometers has its bulb covered by muslin or other porous material dipping into water in a small vessel. This is generally called the wet thermometer, to distinguish it from the other which has no such arrangement attached to it. The porous fabric ' sucks up ' water and causes it to evaporate, and as evaporation requires latent heat, a fall in temperature occurs, consequently the more the air is unsaturated the greater the evaporation and the lower the temperature indicated by the wet thermometer. The other instrument measures the ordinary temperature of the air at the time. If the air is really saturated, it is at the dew point, and the two thermometers give the same reading, but if the air is far from saturation the two thermometers give very different readings. If the actual dew point is to be determined by means of this instrument reference must be made to certain tables, but by the use of **Daniell's hygrometer** (Fig. 188) the dew point can be found directly by experiment. In this a glass bulb (*B*) is covered with muslin and a little ether or other volatile substance is poured on it. By evaporation the temperature is lowered and moisture is deposited upon a second bulb (*A*) containing a thermometer which shows the temperature at which the moisture begins to appear.

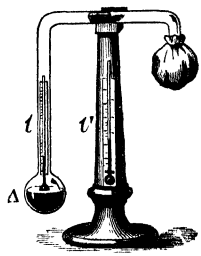
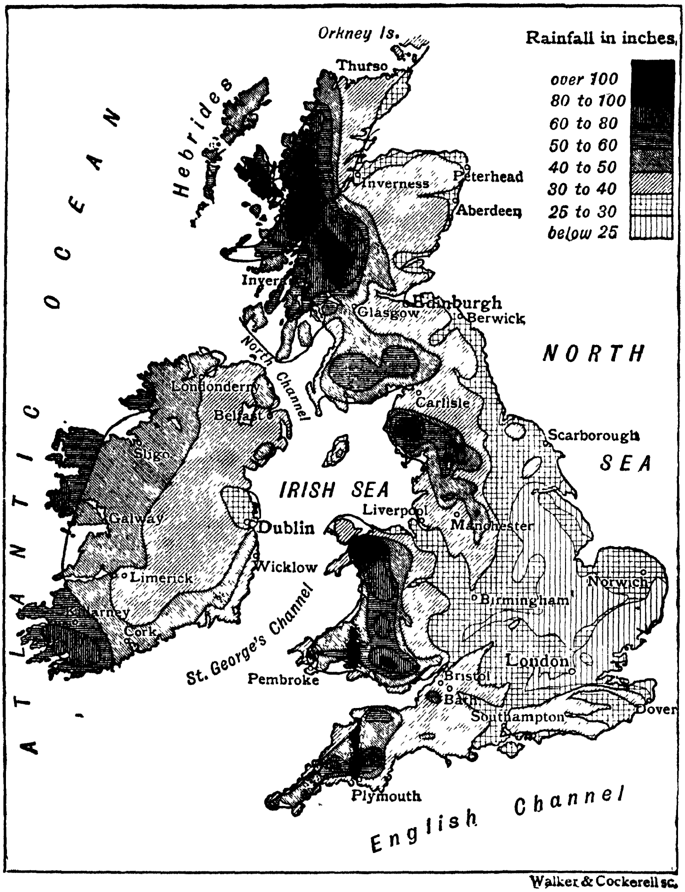


FIG. 188.—DANIELL'S HYGROMETER.

When large masses of air are cooled sufficiently, water vapour is changed to liquid or condensed to water, and **clouds** are formed. The drops of water are at first too small to fall as rain, but as further cooling and consequent condensation proceed, the drops become larger and eventually fall. Air is cooled by its rising upwards; such ascending air reaches altitudes where the pressure is reduced and it expands. *When any gas expands heat is absorbed and the temperature falls.* Conversely, descending air contracts and gives out heat. Any cause which deflects air upwards leads to its being cooled by expansion, and this explains why mountain ranges are generally the places where there are heavy falls of rain or snow. The western side of the British Isles has a much heavier rainfall than the eastern side because

the high land there deflects the westerly winds upwards (Fig. 189). Other factors may produce similar effects. There are no mountains in the central portion of the Amazon basin in South



Walker & Cockerell sc.

FIG. 189.—MAP SHOWING THE AVERAGE ANNUAL RAINFALL OF THE BRITISH ISLES.

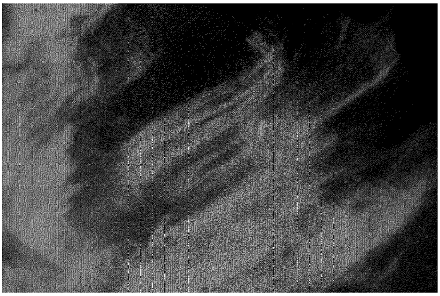
America, but the air there ascends because the heated ground causes an updraught; consequently there is a heavy rainfall in that region.

Ascent of air, then, is the main cause of cloud formation and of rain. The highest clouds, at an altitude of about six or seven miles, appear as white feathery masses known as **cirrus.** These are composed of ice particles since at that height the temperature is below 0° C. The temperature, pressure, and humidity of the upper air has been investigated by means of sounding balloons which carry small but efficient instruments up with them. The balloons burst but the protected self-registering instruments fall, are recovered, and their records obtained. It is now known that *all of the conditions which we call weather are produced within six or seven miles of the earth's surface.* Beyond this altitude there is a region free from clouds but intensely cold.

In summer we often see great white billowy clouds called **cumulus,** and these may either slowly disappear or develop into darker clouds called **cumulo-nimbus,** almost black at the base and usually associated with thunderstorms and heavy falls of rain. The basal parts of clouds of this type are roughly at a height of ¾ mile, though the upper whiter portions may extend to 3 miles. At greater heights a combination of cirrus and cumulus occur, and these are rather curved white clouds, sometimes producing the appearance of 'mackerel sky.' An alternative name for these is **alto-cumulus.** The long low-lying clouds often seen at sunset in summer are called **stratus.**

Condensation of water vapour depends upon there being dust or other particles in the air. Each drop of rain is formed around such a small nucleus, and, in the vicinity of large cities where great quantities of smoke are passed into the air, a fog may be produced. Fogs and mists are formed near the ground and result from the fact that the air just above the ground happens to be cooler than that above. Water is normally transparent, but the opaque character of fog particles is due to the large number of impurities in the air, chiefly sulphur, carbon, and ammonia.

When the temperature is sufficiently low, snow may fall instead of rain, and in certain conditions, particularly those associated with thunderstorms, hail is produced. Some hailstones show a structure composed of concentric layers of ice, indicating repeated alteration of temperature due to different levels reached as the



'Mares Tails'—Cirrus

Cumulus

Cumulo-Nimbus

Fig. 190.—Types of Clouds.
(From photographs by Mr. G. A. Clarke, Aberdeen.)

hailstone has repeatedly fallen and then carried upwards again. Vertical oscillations of this kind also influence the size of hailstones; in some thunderstorms hail as large as walnuts falls and does great damage to vineyards, greenhouses, etc.

SOME PRACTICAL RESULTS OF LATENT HEAT OF VAPORISATION

Heat must be supplied to a liquid in order to vaporise it, and this heat is generally obtained from surrounding objects; hence evaporation is accompanied by a fall of temperature. A surgeon employs an ether spray to produce local anaesthesia, or insensibility to pain, in some minor operations. Ether is sprayed upon

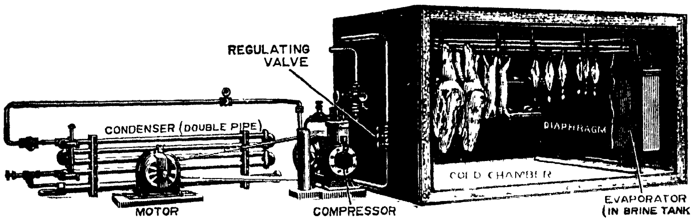


FIG. 191.—REFRIGERATING APPARATUS AND COLD STORAGE FOR THE PRESERVATION OF MEAT.
A LOW TEMPERATURE IS PRODUCED BY THE EVAPORATION OF LIQUID AMMONIA.

the affected place and its rapid evaporation takes sufficient heat from the place to produce a numbness or temporary insensibility. Butter may be kept cool by placing it under wire netting supporting a porous fabric, the ends of which are immersed in water. The arrangement is similar to the wet bulb thermometer of a hygrometer, evaporation of the water producing a fall of temperature. A person receives a chill if he sits about in wet clothes, because, as these clothes dry by evaporation of the water, much heat is taken from his body to supply the necessary latent heat. He should either remove the clothes before they dry, or if this is not possible, he should take sufficient exercise to generate heat to balance that lost.

In commercial activities, large quantities of artificially produced ice are employed, and in other cases air at a very low temperature

is necessary. For example, the meat exported from the Argentine, New Zealand, etc., is carried by ships specially fitted with refrigerators or cold chambers in which a low temperature is produced artificially. In all warm countries large quantities of meat, fish, game, and other perishable goods must be preserved in a similar manner. Modern machinery used to produce low temperatures makes use of two facts described above, (1) the cooling of a gas by expansion, dynamical cooling as it is sometimes called, and (2) the heat absorbed by a liquid as it evaporates.

The substance commonly employed is liquid ammonia, and this is obtained by allowing ammonia gas to expand (compare liquid air, Chapter XXX). By means of a pump producing a suction effect in the space above some liquid ammonia, some of it is vaporised, and this leaves the remaining liquid cooler, and, of course, the process can be continued. If the liquid ammonia is placed in pipes surrounded by a brine solution, the latter is cooled and its influence can be employed either to produce quantities of artificial ice or to cool a chamber containing meat or other perishable goods. Solutions of brine or of calcium chloride remain liquid at temperatures below 0° C., and hence are useful as a means of producing low temperatures by convection. Other details of an ammonia refrigerating plant are given in Chapter XXXVI.

CHAPTER XXII

LIGHT AND COLOUR

WAVES IN MATTER AND IN ETHER

We see things because they send light to our eyes. *Light itself is not visible* ; it is the object illumined by the light that is seen. When we speak of ' seeing a light ' we are not stating things correctly, the things seen being the white-hot particles of matter which originate the light. A candle flame is visible because its heated particles emit light, but a house is seen because it reflects light obtained from the sun during the daytime, or from a lamp or the moon at night. The sun, stars, candle flames, and electric lamps are all self-luminous or give out light of their own, but most relatively cold objects—the moon, houses, and nearly all the objects we come in contact with in daily life—are not self-luminous ; they are seen because they reflect light obtained from some luminous source.

In a self-luminous object, light is nearly always accompanied by heat and by other radiations which can neither be seen nor felt, though they can affect photographic plates or operate electrical devices. Most sources of light require to be at a very high temperature before they become luminous, for example, an incandescent mantle of a gas burner, and then only a small portion of the radiation is light, most of it being in the form of heat. A few cases of ' cold ' light are known, but this phenomenon, known as **phosphorescence**, is produced by certain insects, such as the beetle commonly called a glow-worm, and by the minute marine organism called *Noctiluca*, which causes the phosphorescence of the sea. Another example is afforded by the cool burning of certain gaseous compounds of phosphorus due to the decomposition of organic matter. The glow called

Will-o'-the-wisp, seen above marshy places, and the light emitted by bad fish originate in this way.

Light itself is a kind of wave motion travelling at great speed through the ether of space. One of the most commonly known examples of wave motion is the formation of ripples on water when a stone is thrown into a pond. These ripples proceed outwards in horizontal circles away from the place where the stone enters the water, and give the impression that the water itself is moving towards the edge of the pond. But this is not the case; *the wave form, or succession of crests and troughs, is all that travels to the pond's edge*, the water itself merely moving up and down, as is shown by floating objects, such as pieces of wood. Waves on the sea are similar, though it must be realised that a sloping shore causes the up and down motion to be partly translated to a forward and backward movement. In deeper water, where this disturbing factor is absent, the water merely rises and falls, each particle moving up and down slightly later than the preceding particle, so that the wave motion takes a certain time in traversing a definite distance. Ocean currents and tides cause a movement of the whole body of water independently of wave motion.

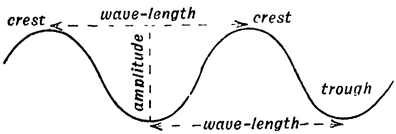


FIG. 192.—DIAGRAM REPRESENTING WAVE-LENGTH AND AMPLITUDE.

Though wave motion in water is large, slow, and rather complicated, it may serve to illustrate certain facts concerning wave motion in general, whether it occurs in ordinary matter, such as water and rocks (earthquakes, Chapter IV), or in the finer universal medium called ether, which extends through all ordinary matter and all apparently empty spaces. If the air is pumped out of a glass vessel, light can still pass through it because the ether is still there. Continuity is a characteristic feature of the ether, whereas ordinary matter is discontinuous, even a lump of iron or stone being composed of particles separated by innumerable minute spaces.

The waves of the sea appear as ridges or crests separated by intervening troughs. The horizontal distance between one

crest and the next is called the **wave-length,** which in this case may be three or four up to hundreds of feet (Fig. 192). The actual vertical distance through which the water rises and falls is known as **amplitude.** The horizontal distance traversed by the wave motion itself in one second is called the **velocity,** which in the case of water is very small, but *in the case of ether waves is very large, about* 186,326 *miles.* All ether waves, whether those we call light, or others which are known as electro-magnetic waves, travel at this great speed.

When we study sound, we shall find that there are *longitudinal* waves in which particles of air move forwards and backwards, but in those we are now considering the up and down motion is *transverse* or at right angles to the direction in which the wave motion as a whole travels. In some ether waves the wave lengths are exceedingly minute, merely a small fraction of one millionth of an inch, some such waves being those popularly termed **X-Rays,** also called **Röntgen** rays, after the man of science who discovered and named them.

The term 'ray' is often used to denote a wave motion which radiates or spreads rapidly from a source of origin. Thus we have rays of sunlight, radiant heat, ultra-violet rays used in medical practice, and so on. Light waves are those transverse motions of the ether which produce the sensation called sight, when they affect the sensitive nerves of the eye. The wave-lengths of these particular waves vary from about 16-millionths to about 30-millionths of an inch, and all the other ether waves of larger or smaller wave-lengths are not perceived by means of sight, though some of them can be felt as heat, others can affect photographic plates, and still others can produce electric currents in the aerial of a wireless receiving station.

The waves used in wireless telephony are very long, usually hundreds of yards in length, and in this they differ considerably from the shorter waves producing light. But they travel through space at the same rate, 186,326 miles per second. It follows from this that there is a very much greater number of oscillations per second in the case of light waves than there is in the case of wireless waves, for it takes far more short waves than long waves to span 186,326 miles. The number of waves or

oscillations per second is known as the **frequency**, and the smaller the wave-length the greater the frequency. Even in the case of the longer light waves which produce red light, there are considerably more than 7000 million oscillations per second, violet light has about double this number, and the waves of other colours have intermediate frequencies. Even with much longer wireless waves the frequency is still great. Though the wave-length of the London wireless broadcasting station, 2LO, is 361·4 metres, about $2\frac{1}{2}$ million of such oscillations occur in one second.

Sufficient has been said to show that light and wireless waves are both transverse oscillations of the ether and that they differ in wave-length and frequency.

If we refer again to the illustration afforded by waves in water, we can realise that just as the wall of a sea-front sends back or reflects water waves, so mirrors and other objects reflect light waves, mirrors of course doing this better than other things. But the analogy between motions in water and those in the ether

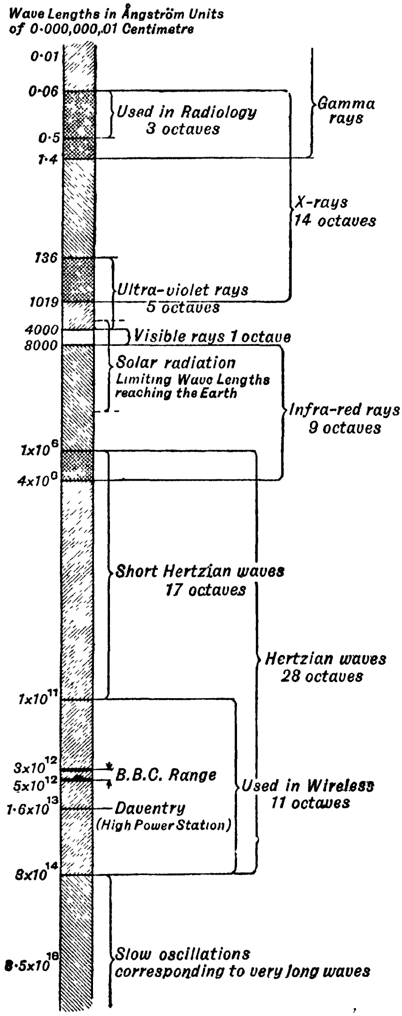


FIG 193.—THE ' GAMUT ' OF ETHER WAVES.

ADAPTED FROM A CHART PREPARED FOR THE ROYAL SOCIETY EXHIBIT AT WEMBLEY, 1925.

must not be carried too far. Waves in water are disturbances more or less confined to the surface layers, and the motion spreads in a horizontal direction only. Ether waves, whether those of light or others of different wave-length, radiate outwards in all directions through the space surrounding the source of origin, unless, of course, an object in the path of some rays obstruct their passage. When unimpeded, the advancing wave front is somewhat similar to a very rapidly expanding spherical shell, if one is permitted to make an analogy between spaces traversed by ether vibration and the forms assumed by ordinary matter.

In any region shielded from light rays by an object there will be a shadow of the object. This fact affords valuable proof concerning the roughly spherical shape of the earth, since its shadow on the moon is always circular. Eclipses have been described in Chapter II.

The relation between the form of the shadow and the shape of the object depends upon the fact that light rays proceed in straight lines, or at any rate in what appears to us to be straight lines. As **Einstein** has shown, such conceptions as straight

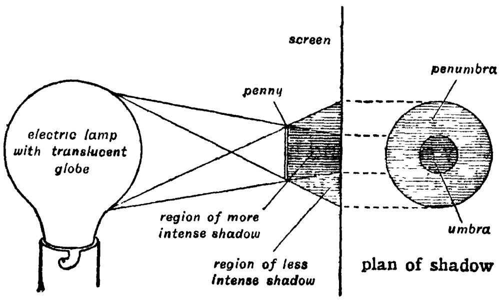


FIG. 194.

WHEN AN OBJECT IS SMALL COMPARED WITH THE SOURCE OF LIGHT, AND WHEN A SCREEN IS SUITABLY PLACED, THE SHADOW CONSISTS OF UMBRA AND PENUMBRA

lines are *relative* and not absolute, even rays of light from distant stars being slightly bent aside by the influence of the sun. The character, *i.e.* not shape but intensity of a shadow, is mainly determined by the size and form of the source of light. If the source is a mere point, an object casts on a screen a shadow which

is uniformly dark. When the luminous source is large, such as the sun, the shadow of an object will generally consist of a darker portion or **umbra**, due to the complete obstruction of all rays, and a less intense portion or **penumbra** due to the obstruction of some, but not all of the rays, as the illustration shows (Fig. 194). Any object which effectively prevents the passage of light rays through it is said to be **opaque**. Most common materials—wood, iron, stone, etc.—afford examples. A substance such as clear glass which permits light to pass so that objects are seen clearly through it is described as **transparent**, but if only some of the light gets through so that clear vision is not possible, as in the case of ground glass or greased paper, then the object is said to be **translucent.**

COLOUR AND THE SPECTRUM

When light falls upon an opaque object it is either absorbed or reflected; most objects absorb some wave-lengths and reflect others. The energy of absorbed light is usually changed to heat. If nearly all the light from sunlight or other source of so-called white light is reflected the object appears white; if none of it is reflected, the object appears dull black. A black shiny object absorbs most of the light, but reflects a little, and the property we call lustre depends upon the character of the surface reflecting the light. Very smooth and highly polished surfaces reflect light so perfectly that images or pictures of things in front of them can be seen, and the reflecting surface is known as a **mirror.** More will be said about this later.

Light received from the sun is of a complex nature, being composed of waves of different lengths. That daylight is composed of several wave-lengths which separately give different colours can be shown fairly easily. In a darkened room a beam of sunlight is permitted to enter through a narrow slit in a shutter. This beam of light is passed through a triangular glass prism, and in going through it the light is bent aside or **refracted** (Fig. 195). On emerging from the glass into the air again the light is again bent farther in the same direction. A white screen is placed in the light which has emerged from the prism, and on this screen is

seen a continuous band of colours, ranging from red at one end to violet at the other. Between the red and the violet are successively arranged, orange, yellow, green, blue, and indigo, and one colour merges rather indistinctly into the next. This band of colour is known as the **spectrum** of sunlight, and it is clear that what we miscall white light is really a combination of different wave-lengths capable of producing different colours when the composite light is analysed or split up by means of a glass prism.

The discovery of this action of a prism on sunlight was one of the many achievements of Sir Isaac Newton, and we have a most

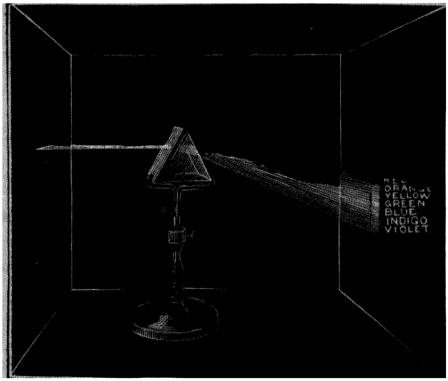


FIG. 195.—REFRACTION AND DISPERSION OF SO-CALLED 'WHITE' LIGHT BY A PRISM.

valuable practical application of this in the spectroscope, an instrument used extensively in astronomy and chemistry, as explained in Chapters I. and XXXVIII.

The colours of the spectrum are produced by light of different wave-lengths, the shorter violet waves being refracted by the glass more than the others, and the red waves are the least refracted of those perceived as light. As explained above, there are other still shorter waves beyond the violet end of the spectrum and longer ones beyond the red, but they are not visible. The separation of the various wave-lengths by a prism is called **dispersion.**

If an opaque object appears coloured, the colour is due to the reflection of only those wave-lengths which produce that particular colour. Thus a red rose is red because it reflects the red rays and absorbs the other rays of daylight. The colours of such objects are due to selective reflection and absorption. A man painting a motor car blue is covering the car with a substance which reflects only those wave-lengths which give the sensation called blue; all the other wave-lengths are absorbed. The numerous and varied tints seen in a garden of flowers or in fabrics are due to the reflection of various combinations of wave-lengths of the primary colours in the spectrum.

The production of colour in transparent substances, pieces of red glass for example, is rather different. In this case the glass allows red waves to pass through but not others; the glass also appears red when one looks *at* it and not through it, as it also reflects only red rays.

We have considered only cases in which the light employed is of the composite kind commonly called white, the standard example being daylight; but what happens if the source emits light having a wave-length corresponding to a certain colour only? When illumined by red light only, objects normally red in daylight are seen in their true colour; a blue object would appear nearly black in such red light because the object normally reflects only blue, and there are no waves of this length to be reflected. The normally blue object absorbs the red rays emitted by the source. For similar reasons, some coloured lamp shades produce curious effects; for example, a person's face appears ghastly when seen by light passing through a blue shade, since there is an absence of red and warm tints which produce the normal healthy appearance of the face.

We are now in a position to understand why the colours of fabrics, curtains, carpets, etc., usually appear in artificial light different from their normal appearance in daylight. The light emitted by electric lamps, gas flames, etc., does not contain the waves of various lengths in the same respective proportions as found in daylight. The longer red waves are present in greater proportion than in daylight, but on the other hand the proportion of blue waves is smaller. From this it follows that a red carpet

will reflect relatively more red rays by artificial light and will appear to be of a stronger red at night than in the day time, but a blue carpet is a more intense blue in day time than at night. The quality of other colours will be modified; for example, purple, which contains both red and blue, will appear to have a higher proportion of red when seen by artificial light.

Rectifying devices are often used to make the artificial light as much like daylight as possible. A daylight effect may be produced either by passing the artificial light through a glass bulb so coloured as to block out some of the red and add blue, or by placing a suitably coloured reflector above the lamp. Such a reflector will adjust the relative proportion of the wave-lengths by means of patches of various colours, chiefly blue, with smaller amounts of green and yellow. If a coloured fabric is to be matched accurately it is better to employ ordinary daylight rather than trust any type of 'daylight' lamp.

ATMOSPHERIC COLOUR EFFECTS

The sunlight which illumines the earth during the greater part of the day is composed of all wave-lengths from violet to red, but at sunrise and sunset certain colours, chiefly yellows and reds, are seen because the wave-length producing the other colours of the spectrum fail to reach us. Enormous numbers of very minute particles of dust and water vapour scatter or reflect the blue vibrations, but colours due to larger wave-lengths, the reds and yellows, pass on, since the dust and other particles are not large enough to reflect them. A dust particle cannot reflect a wave-length greater than the size of the particle itself. At sunrise and sunset the red and yellow rays reach us, the blue rays do not, the great thickness of air, and consequently the greater number of dust particles, intercepting the light at such times being decisive factors. Snow-clad peaks of mountain ranges illumined by the red rays of dawn or sunset is one of the grandest sights in the world. Remarkably vivid colour effects are sometimes due to the great increase in the quantity of dust in the air by volcanic explosions, such as that of Krakatoa in the year 1883, when a series of extraordinarily beautiful sunsets were seen.

The sun when seen through a thin mist of water vapour appears red because the shorter wave-lengths are reflected away from us. The blue colour of a clear sky is also caused by the reflection of blue wave-lengths, but in this case these waves reach us because the reflecting particles are above and not roughly between us and the sun, as they are at sunset or sunrise. If there were no particles to reflect the rays the sky would appear black. The colour of clouds depends upon the relative propor-

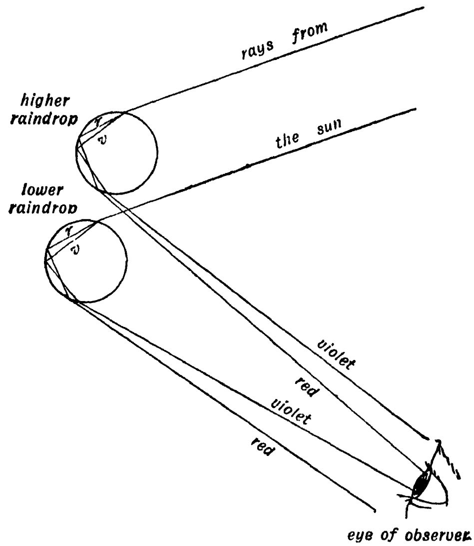


FIG. 196.—DIAGRAM ILLUSTRATING THE ACTION OF RAIN-DROPS IN FORMING A PRIMARY RAINBOW.

tions of the various wave-lengths absorbed or reflected, and this depends upon the size of particles forming the cloud.

These effects are due to reflection, but a **rainbow** is produced by combined reflection, refraction, and dispersion, drops of rain acting as if they were so many glass prisms splitting up the composite sunlight which enters them (Fig. 196). In order that a rainbow shall be seen certain conditions must be fulfilled. The sun must be above or behind the observer and a falling shower of rain must be in front of him. As a ray of light enters a drop of

water refraction and dispersion take place, the light being split up and the different wave-lengths separated by unequal refraction. On reaching the back of the drop of water reflection occurs, the waves being sent forward, and on emerging from the drop the dispersion of the colours is increased. The reflection by the back of the raindrop reverses the order of the colours, so that violet occurs on the inner side of the rainbow, and red on the outside. Since the positions of all those drops which can produce a visible effect on a given observer are situated along arcs of circles, the rainbow has the characteristic curved form. Sometimes another outer and fainter bow is seen, and in this the order of colours is the reverse of that in the primary bow. On a bright sunny day a small rainbow can be produced by means of a garden hose, provided the falling shower, sun, and observer are all in the correct relative positions.

CHAPTER XXIII

ILLUMINATION

THE amount of light received by an object from a luminous source depends upon three things—the illuminating power of the source, the size of the object illumined, and the distance separating the source from the object. Generally, the degree of luminosity of a source largely results from its temperature; the higher the temperature the greater the amount of light emitted by unit area, and, of course, the greater the size of the luminous object the larger the total amount of light radiated. Though the earth is 93,000,000 miles distant from the sun, the light we receive is considerable because the sun's temperature is enormously high (see Chapter I) and its size is great.

The good illumination received from an electric arc lamp is due to the high temperature of the arc, about 3500°; the size of the arc itself is small. The temperature of an ordinary electric lamp must be sufficiently high if the filament is to be white hot and not merely red hot. On the other hand, a luminous bunsen flame is cooler than a non-luminous flame, so that luminosity does not always increase with temperature.

The relation between the total amount of light received by an object and its size is quite simple; if there are two things at equal distances from the same source of light, but one has four times as big a surface as the other, it will receive four times as much light, provided that the angle at which the light rays strike the two objects is the same.

The relation between the distance of the source and the amount of light received by the object is not quite so simple, as an easy experiment shows. A piece of cardboard, or preferably of sheet metal, having a small hole pierced in it,

is placed in front of a lamp (Fig. 197). Light passes through the hole and proceeds forwards in straight lines which diverge wider apart as they extend farther. Now a second piece of cardboard having a square hole about one square inch cut in it is placed in the pathway of these rays at a suitable distance from the first piece of cardboard. If this distance is two inches, a third cardboard is placed at a distance of four inches from the first piece. On this screen an area of four square inches is illumined by light which passes through a hole of one square inch at half the distance from the source. It is obvious that *at double the distance the same light rays will illumine an area four times as large as that illumined by them at the original distance.* This being the case, the intensity of light or the amount received per square inch at this greater distance is only $\frac{1}{4}$ of that received at the other position half the distance from the source. In the case of light spreading in all directions this relation is true for all distances and affords another example of the law of inverse squares. *The intensity of illumination varies inversely as the square of the distance separating the source from the object.* In scientific work this intensity of illumination is measured by the amount of light which falls on a square centimetre of surface placed at right angles to the direction along which the rays proceed.

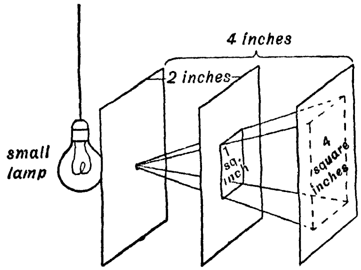


FIG. 197.—A METHOD OF ILLUSTRATING THE LAW OF INVERSE SQUARES.

The inverse square law is of great use since it enables us to make careful comparisons of the respective illuminating powers of various sources of light.

If actual measurements are to be made, some standard source of light is necessary, and formerly, when candles were more important than they are now, the illuminating powers of lamps, etc., were expressed in terms of candle power, or the light emitted by a **standard candle.** Such a candle was composed of sper-

maceti wax, of which 120 grains were consumed in one hour, and six candles weighed one pound. At the present time a **standard pentane lamp** burning pentane, a product derived from paraffin, is employed. Properly adjusted, such a lamp is equal to ten standard candles, and we still describe lamps as being of so many candle power.

When either candle or lamp is used as a standard, the illuminating power of any other source of light is measured by a process based upon the law of inverse squares, and the instrument by which the measurement is made is called a **photometer.** Some of these instruments yield much more accurate results than others. One of the older types, not much used to-day but nevertheless of considerable interest, is known as **Rumford's shadow photometer** since the distances of various sources of light are adjusted so that the shadows of a rod appear of equal intensity. A vertical rod just in front of a white screen casts a shadow upon it when a standard candle is placed at a convenient distance from the screen. The lamp, the candle power of which it is desired to measure, is placed so that the shadow formed appears equally dark as the other one, hence the two sources of light, candle and lamp, are then illuminating equally the portions of the screen around the shadows, and the relative powers of the lights are in proportion to the squares of the respective distances. If the candle is two feet from the screen and the distance of the lamp is four feet, the illuminating powers are represented respectively by the numbers 4 and 16, and the lamp is said to be of four candle power. The shadow method is liable to inaccuracy since it is not easy to say exactly when the shadows are equally intense, and people differ in their powers of observation.

More accurate results can be obtained from the use of **Joly's photometer,** which consists of two small slabs of paraffin wax equal in thickness and separated by a sheet of tinfoil (Fig. 198). The

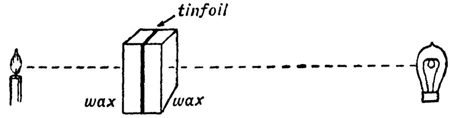


FIG. 198.—JOLY'S PHOTOMETER.

standard light is placed at a convenient distance in front of one piece of wax, and the light to be tested is placed in front of

the other and its distance varied until the two pieces of wax viewed from the side appear equally illumined. As before, the relative powers of the sources of light are proportional to the square of their respective distances. It must be realised that *the power of a source is one thing, and the illumination at a place is another,* the latter varying *inversely* with the square of the distance from the source.

Another interesting though very simple type of apparatus is **Bunsen's grease spot photometer.** If two sources of light are placed one on either side of a sheet of paper containing a small greased area, the grease spot becomes invisible when viewed from either side if the two sources are at such distances that the illumination of both sides of the paper is equal.

This is the principle of the **Benjamin lightmeter** employed for measuring the degree of illumination in class rooms, workshops, etc. This consists of a long box containing a lamp near one end, and rays from this lamp strike a translucent screen above at different angles and at different distances. Consequently the illumination due to the lamp is different at different parts of this screen, being greatest just above the lamp. A sliding cover having a translucent spot is moved along the screen until the spot becomes invisible; the external illumination is then equal to that of the lamp at the place where the translucent spot is situated. If the intensity of illumination due to the lamp at different positions along the screen has been determined and calibrated previously, the degree of external illumination can be read directly from a scale. Practical units of light intensity are required, and those employed are known as **foot candles.** *One foot candle is the degree of illumination received by a vertical white screen placed at a horizontal distance of one foot from a standard candle.*

According to the law of inverse squares, 100 standard candles or one 100 candle-power lamp produces an illumination of one foot candle at a distance of 10 feet. An electric lamp of this power is commonly used in sitting rooms of average size, but of course the illumination on the wall will be one foot candle only when the wall is 10 feet from the lamp. Lamps of the same candle power used in rooms of equal size produce different

degrees of illumination because of variation in the colour and surface of walls, furniture, and effects, since different substances absorb and reflect varying quantities of light. Dark wallpapers absorb more than pale ones, consequently a source of light must

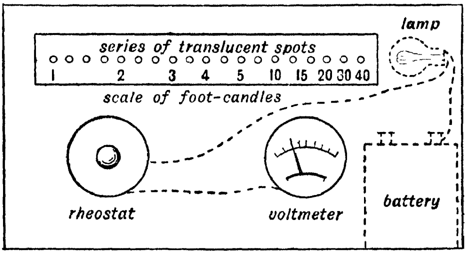


FIG. 199.—PLAN OF A LIGHTMETER.
WHEN THE VOLTAGE, HENCE THE LAMP, IS PROPERLY ADJUSTED, THE ILLUMINATION IS READ DIRECTLY FROM THE SCALE.

be of a higher candle power to produce good illumination in a room having a dark colour scheme than that required for a room brightly furnished and decorated. The following examples give some idea concerning the proportion of light reflected by wallpapers, etc.:

Ordinary white paper	reflects	about	80 %	of	incident	light.
Clean white wood	,,	,,	50 %	,,	,,	,,
Blue paper	,,	,,	25 %	,,	,,	,,
Brown paper	,,	,,	14 %	,,	,,	,,
Black cloth	,,	,,	1·5 %	,,	,,	,,

The degree of illumination required depends upon the purpose for which the light is used, some occupations requiring more light than others, and the figures given below may be considered normal for the various purposes quoted:

watchmakers require 12 or more foot candles;
for sewing dark material from 8 to 10 foot candles;
draftsmen, from 6 to 8 foot candles;
shops (clothing) from 4 to 7 candles;
school classrooms from 2 to 3 foot candles;
ordinary sitting rooms require about 2 foot candles;
churches and assembly halls require 1 to 1·5 foot candles.

It is possible to read printed matter of average size with an illumination of only one quarter of a foot candle, but more light than this is desirable if eye strain is to be avoided.

We must distinguish between good diffused light and **glare,** the latter being caused by a *high degree of luminosity per unit area of the source of light.* If the same amount of light from a motor head lamp could be radiated from a larger surface the glare would be reduced. Alabaster bowls often placed below sitting room electric lamps diffuse the light and cause much of it to be reflected by the ceiling, thus producing a 'soft' effect practically free from glare. The filament of the lamp is of small area yet emits light of a hundred candle power, consequently glare results unless the lamp is screened.

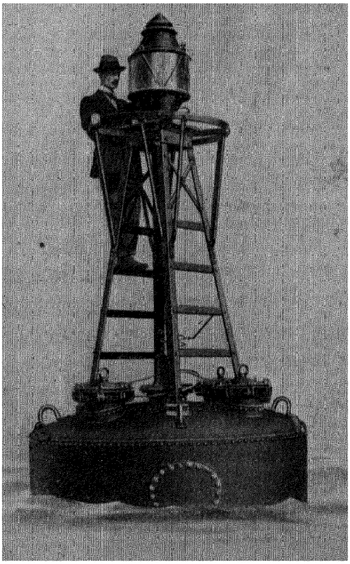


FIG. 200.—A LUMINOUS BUOY USING ACETYLENE.
(By courtesy of Messrs. Chance Bros.)

In good illumination the light should be 'white,' that is, it should be composed of the various colour wave-lengths in the same proportions as found in sunlight. Most artificial lights do not contain the colours in correct proportions, hence the use of compensating devices mentioned in the previous chapter.

In towns electric light and coal gas are used for lighting purposes. With modern burners the value of coal gas depends upon its heating power, light being produced by a mantle rendered white hot by the heat of the flame. In addition to the use of oil, country house lighting may now be effected by the use of **electricity, petrol-air gas,** or **acetylene.** The machinery

necessary for the production of electric light consists of a dynamo, a petrol motor to work it, and some accumulators (Chapters XXVII and XXVIII). Petrol-air gas consists of air mixed with about 5 per cent. of petrol vapour, such a mixture forming a safe non-explosive and non-asphyxiating substance. As in the case of coal gas, incandescent mantles are employed. The generating apparatus contains a carburettor for vaporising the petrol, means of mixing it with air in the correct proportion, and a container for storing the mixture under the required pressure.

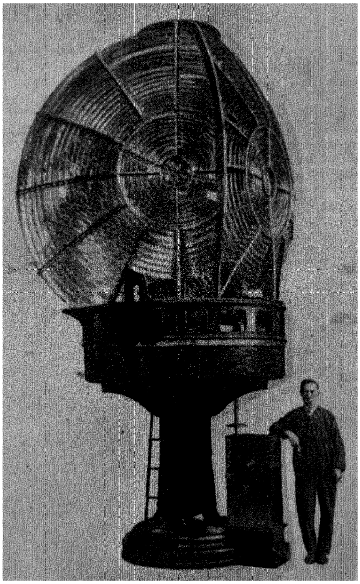


FIG. 201.—LIGHT-HOUSE APPARATUS.
(By courtesy of Messrs. Chance Bros.)
See also Chapter XXV.

Acetylene can be generated by letting water drip at a definite rate on **calcium carbide**, as in the acetylene lamps used on bicycles and motor-cycles or it can be obtained dissolved in a liquid hydrocarbon called **acetone** contained in large steel cylinders. At normal atmospheric pressure acetone dissolves about 25 times its own volume of acetylene. In this form it is much used for other purposes, such as luminous buoys at sea and oxy-acetylene welding. Acetylene burners do not require mantles, and the light obtained approximates in character to that of sunlight. For country house lighting, electricity is the most expensive, and acetylene is the least costly so far as initial outlay is concerned. In a complete installation for 20 lights of the usual candle power, electricity would cost about £142, petrol-air gas about £86, and acetylene £60.

For certain purposes, lights of thousands or even millions of

candle power are required. In optical projection lanterns, either electric arc lamps or the light from an incandescent cylinder of lime is employed, in the latter the heat necessary to render the lime luminous being obtained from the combustion of coal gas in oxygen, the latter being stored under pressure in a steel cylinder. The electric arc is used in searchlights and in the larger lighthouses, such as that of St. Catherine's in the Isle of Wight, which has a candle power of several millions. Smaller lighthouses, harbour lights, etc., make use of vaporized oil, which renders a mantle burner incandescent. For outdoor work as performed on railway tracks, and for certain naval and military purposes, a light which remains steady in spite of wind and rain is required. Such illumination is obtained from a self-contained and portable apparatus known as the **Wells Light** (Fig. 202). In this, oil spray blown horizontally gives a perfectly steady light varying in intensity from 500 to 3000 candle power according to the size of apparatus.

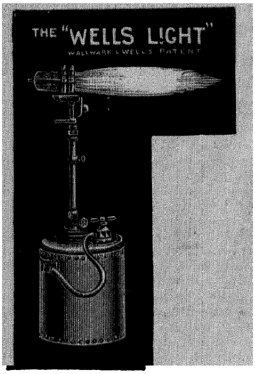


FIG. 202.—A LIGHT NOT INFLUENCED BY WIND AND RAIN.

(By courtesy of Messrs. Wells & Co. Ltd.)

CHAPTER XXIV

REFLECTION AND MIRRORS

A mirror or **looking-glass** is a most useful article, enabling one to see things which would otherwise be invisible. For example, how can a man see to shave himself, or a dentist examine teeth properly, without the aid of a suitable form of mirror? A looking-glass functions as it does because it is a good reflector of light.

The light which falls upon an object is partly reflected and partly absorbed. A piece of white paper reflects most of the light striking it, but a piece of dull black paper absorbs nearly all light reaching it. Black letters on the page of a book absorb light, while the surrounding white ground reflects it, hence the contrast which makes reading possible. Though a piece of white paper reflects a good deal of light it does this in a very irregular manner, the rays which strike the paper being sent back in general disorder, some proceeding this way, some that way, and so on (Fig. 203). If a lighted candle is held in front of such a piece of paper, a picture or **image** of the candle flame is not seen as would be the case if it were held in front of a mirror. The rays reflected by the paper are too disorderly for an image to be formed, but

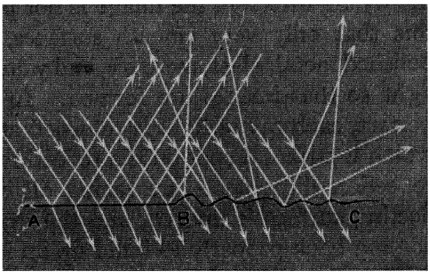


FIG. 203.—REGULAR REFLECTION OF LIGHT (BETWEEN A AND B) AND IRREGULAR REFLECTION (BETWEEN B AND C).

THE REFLECTING MATERIAL BEING IN THIS CASE A BLOCK OF GLASS, MANY RAYS PASS INTO THE GLASS AND ARE REFRACTED.

in the case of a mirror the rays are perfectly or accurately sent back, so that they appear to reconstruct a picture of the object which sends them to the mirror. The degree of perfection with which light rays are reflected evidently depends upon the smoothness of the reflecting surface. A rather crude analogy may help to make this point clear. If a tennis ball is thrown at an angle of 45° against a smooth plaster wall, it will rebound, making another angle of 45°, but if it is similarly thrown against a rough wall composed of variously shaped flints, the angle at which it rebounds depends upon the way in which it actually strikes one of the pieces of flint. The piece of white paper is somewhat similar to this flint wall; its surface is irregular though on a microscopic scale, and the light rays which fall upon it are scattered or **diffused** in all directions. The surface of the mirror is similar to that of the plaster wall but, of course, on a microscopic scale.

It takes an enormous number of light rays to form an image, and all of them must be reflected accurately; if many are sent in the wrong direction the image is not produced. It follows from this that only very smooth surfaces, such as those of highly polished metal, glass, mercury, and water, are capable of reflecting light so that images are formed. In reflection, perfect or imperfect, each ray of light is returned at an angle equal to that at which it strikes a spot on the reflecting surface, but in imperfect reflection these spots are facing all directions because the reflecting surface is uneven, and the rays are scattered instead of coming back properly to build up an image.

The formation of images or pictures by mirrors results from the fact that any ray of light is reflected at an angle equal to that at which it strikes a reflecting surface. It is as well to explain this law of reflection a little further. A ray of light striking a mirror at a certain point is said to be *incident* at that point, and is called the **incident ray**. After reflection it is known as the **reflected ray**. If a line is drawn at right angles to the mirror and touching it at the same point as the incident ray, such a line is called a **normal** and in practice this line is used to describe the angles of incidence and reflection. *Thus the angle made by the incident ray with the normal is called the angle of incidence, and*

that made by the reflected ray and the normal is called the angle of reflection, and both of these angles lie in the same plane. The law of reflection is usually stated by saying that **the angle of incidence equals the angle of reflection.** A practical application of the rule is afforded by the case of a flat mirror placed at a corner where two passages form a right-angled bend. In order that a person in one passage may see along the other the mirror must be placed at an angle of 45° to each passage (Fig. 204).

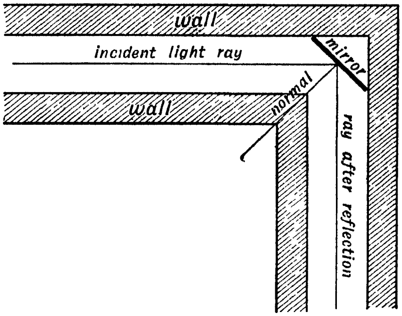


FIG. 204.—A PRACTICAL APPLICATION OF THE LAW OF REFLECTION.

THE MIRROR PLACED AT 45° TO EACH OF THE TWO CORRIDORS ENABLES A PERSON IN ONE CORRIDOR TO SEE ACCURATELY ALONG THE OTHER

The image of a small object, say a pin placed in front of a plane or flat mirror, can be found experimentally and proved geometrically by using the law of reflection. A pin (P) is placed two inches in front of a flat mirror (Fig. 205). Now the pin reflects daylight which falls upon it, and though it is not self luminous it

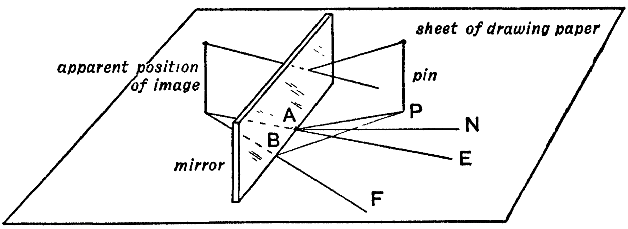


FIG. 205.—THE FORMATION OF A VIRTUAL IMAGE OF AN OBJECT PLACED IN FRONT OF A PLANE MIRROR.

may be regarded as a source of *borrowed* light. It is important to remember this, as all non-luminous bodies, including ourselves, behave in this way, and by means of the borrowed light they can send rays by which they are seen. Consider any ray PA sent

by the pin to the mirror. Draw a normal NA and make the angle NAE equal to the angle NAP. Then AE is the path of the reflected ray, which appears to come from a position behind the mirror. Similarly, consider another ray PB, which after reflection comes back along the line BF and also appears to come from the same position. The paths of any other rays may be traced, and it will be found that after reflection they all appear to come from the position I where an image of the pin seems to be.

Though the picture in our minds is real enough, actually the image is not there since the light rays cannot pass through the mirror, and an image of this sort is said to be **virtual.** Some curved mirrors and lenses can actually bring rays of light together so that they construct a **real** image, but with flat mirrors the images are always virtual; they merely appear to be there.

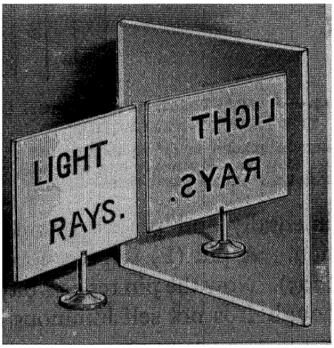


FIG. 206.—AN EXAMPLE OF LATERAL INVERSION.

Another deception must be observed. If you stand in front of a plane mirror you see the image of a person who seems at first sight to be quite like yourself. But that person's right arm is the image of your left arm, in fact the whole of his right side is the reflection of your left side and *vice versa*. This phenomenon is called **lateral inversion** and explains why the writing on blotting paper can be read if it is held before a mirror (Fig. 206). The setting of printers' type can be tested in the same way.

Two other points in connection with these virtual images formed by *flat* mirrors must be realised; *the image always appears to be the same distance behind the mirror as the object is in front of it, and is apparently the same size as that of the object.* Most mirrors used in domestic life are made of glass backed by *mercury* (or by silver in some modern processes), and

if the glass is thick, several images of a lighted match may be seen if it is held quite close to the mirror; this is due to repeated reflection between the inside surface of the front face of the glass and the silvered back of the mirror (Fig. 207).

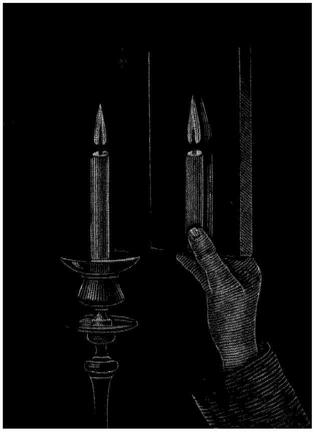


FIG. 207.—MULTIPLE IMAGES OF A CANDLE FLAME FORMED BY A THICK MIRROR.

Plane mirrors are essentially articles of domestic use, but another useful application called a **periscope** consists of flat mirrors so arranged that one is able to see objects the other side of a wall or trench. Two adjustable plane mirrors are placed within a tube, one facing the lower aperture in front of the observer, the other near an upper aperture facing the direction from which the desired view is to be obtained (Fig. 208). When the mirrors are adjusted to the correct angle the observer obtains a view of the country beyond the trench without exposing himself.

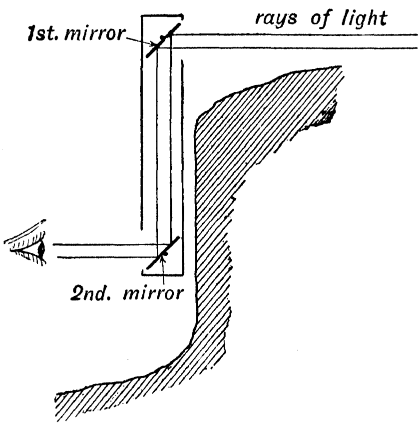


FIG. 208.—A SIMPLE REFLECTING PERISCOPE.

This simple type of periscope is different from the more complicated kind employing a prism which is used on submarines. The action of this refracting periscope is considered later.

Interesting experiments can be performed by placing a pin between two parallel mirrors or between two plane mirrors inclined

at various angles. With parallel mirrors an infinite number of images is possible theoretically. The number with two mirrors at an angle depends upon the size of the angle.

REFLECTING TELESCOPES, SEARCHLIGHTS, AND OTHER DEVICES

What happens when light falls upon a mirror that is not flat but curved? Much depends upon the kind of curvature possessed by the mirror, which may be spherical, that is, part of a sphere, or may be curved without being spherical, an example being an ordinary tablespoon. Many reflectors of considerable practical value are in curved forms called *parabolas*, but at first we must consider the case of spherical mirrors. If the reflecting surface is on the outside of the sphere we have a *convex* mirror, but if the reflecting surface is on the inside the mirror is said to be *concave.*

A motor car is provided with a **convex** mirror placed near the driver, so that he can see a reduced but accurate picture of the road immediately behind him. Since the image is reduced, a small mirror gives a picture showing all objects on a considerable width and length of road. A plane mirror to give satisfactory results would have to be far too large to be convenient.

Now, how is this reduced picture formed by the convex mirror? Consider the case of a single small object, say a pin, placed in front of such a mirror. An image of the pin is seen as if it were behind the mirror, and this image is *virtual*, *as are all other images formed by convex mirrors*. But, unlike the image formed by a plane mirror, it is *smaller* than the object itself and its apparent distance behind the convex mirror is not equal to the distance the object is in front of the mirror. Another fact must be noted. The image is erect, or the right way up; it is not inverted as are some. These facts can be summarised by saying that *all images formed by convex mirrors are virtual, erect, and reduced in size*—a very useful combination of features.

In order to understand how images are formed by convex or other curved mirrors, we must trace the courses of a few of the light rays proceeding from the object to the mirror. A pin is

placed about two inches in front of a convex mirror as shown in the diagram (Fig. 209). As explained above, rays of daylight are reflected by the pin in all directions. Select one of these rays, x, which happens to strike the curved mirror at right angles to the surface. By the law of reflection, this ray is reflected back along the same line, and appears to come from the **centre of curvature** C, or centre of the sphere of which the mirror is a portion. The point p at which this ray strikes the mirror at right angles is called the **pole** of the mirror, and is used in calculations as a starting point to measure distances from the mirror.

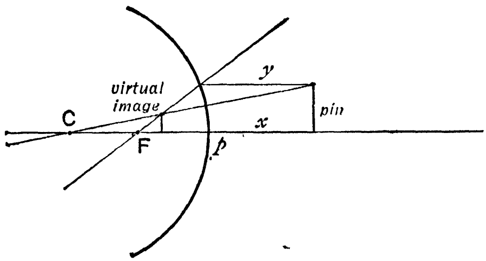


FIG. 209.—THE FORMATION OF A REDUCED VIRTUAL IMAGE BY A CONVEX MIRROR.

Now consider any other ray, y, parallel with the first ray, x. This ray, y, strikes the mirror obliquely, but also conforms to the law of reflection ; it is reflected at an angle equal to that at which it is incident, and appears to come from a point F behind the mirror. *All other rays which are parallel with x and y will also be reflected so that they all appear to come from the point* F, *which is therefore called the* **principal focus** of the mirror. The path of a third ray must be traced if the position and size of the image are to be ascertained. Suppose we select another, which, proceeding from the top end of the pin, is normal to the surface of the mirror. As in the case of x, this ray after reflection appears to come from the centre of curvature, C, and will cut across the apparent path of ray y behind the mirror. This point of intersection marks the upper end of the reduced image of the pin, since the rays from the upper end of the pin appear to come from that point. Thus it can be shown geometrically

that the image is not only reduced in size, but upright, and at a smaller distance from the pole of the mirror than the pin itself is.

One or two other facts concerning curved mirrors, whether convex or concave, should be noted here. The ray we chose first, x, happens to proceed along a line known as the **optical axis** of the mirror, along which are situated the principal focus F and the centre of curvature C. The distance between p and F is called the **focal length,** f, of the mirror, and f is equal to half the radius of curvature. There is a definite relation between the distance of the image, the distance of the object, and the focal length; and if the symbols v, u, and f are respectively used for these three quantities, their relation is expressed by the equation

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}.$$

Note that v, u, and f are all measured in the same units, centimetres or inches.

This formula is true for all spherical mirrors, but when making calculations all distances must be measured from p, the pole of the mirror, and the correct sign, positive or negative, must be employed for each quantity. *Distances measured from the pole towards the source of light are positive, while those measured in the same direction as the incident light are negative.* Hence the focal length f of a convex mirror is always negative. An example will illustrate the use of the equation in calculations.

An object is placed 24 centimetres in front of a convex mirror of 12 centimetres focal length. Find the position of the image.

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f},$$

and in this example $u=24$ and $f=12$. Hence we have

$$\frac{1}{v}+\frac{1}{24}=-\frac{1}{12}, \quad \frac{1}{v}=-\frac{1}{8};$$

therefore $$v=-8.$$

The image appears to be eight centimetres behind the mirror, the minus sign indicating that the position is virtual. *The ratio of the length v to that of u gives the relative size of the*

image. Thus, in this case, v is to u as 8 is to 24, therefore the image is $\frac{1}{3}$ the length of the object.

Now let us see what sort of an image can be obtained by the use of a concave mirror. A useful form of such mirror is known as a **shaving-glass,** but a person has to place himself quite close to it to obtain an enlarged image of his face. If he moves backwards the image disappears. Suppose we consider the case of a pin placed quite close to a concave mirror (Fig. 210).

There is a principal focus, a centre of curvature, and a pole of the mirror as before, also the focal length is half the radius of curvature, but *positive* this time. Let the pin be placed at a distance less than the focal length. As before, draw three rays,

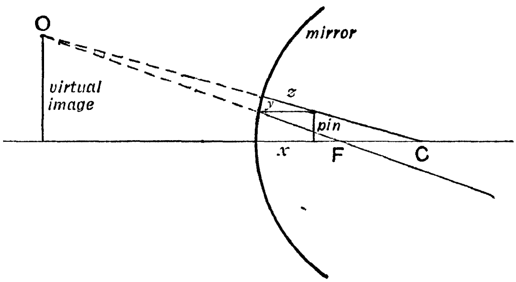


FIG. 210.—THE FORMATION OF A MAGNIFIED VIRTUAL IMAGE BY A CONCAVE MIRROR, FOR EXAMPLE, A SHAVING GLASS.

one, x, passing along the optical axis and being reflected along the same line. A second ray, y, is parallel with x and after reflection will pass through the principal focus, F, while z, which is normal to the mirror, is reflected through the centre of curvature. Now the rays y and z appear to meet at a point O behind the mirror, and the image is virtual, erect, and enlarged. *When an object is placed at a distance less than the focal length the concave mirror functions as a magnifying glass.* Try this with a tablespoon and a lighted match. Although the spoon is not spherical, somewhat similar results are obtained. Compare the image formed by the concave side with that obtained with the convex side.

When the pin is placed at a distance greater than the focal length, but less than the radius of curvature, very different results

are obtained (Fig. 211). The rays proceed to the mirror as before, but it will be noticed that *y* and *z* this time actually meet at a point O in front of the mirror and that the image occurs in front, and is *real*; *it can be caught on a screen of tissue paper held in the correct place.* The rays actually build up an image which is not merely virtual. This image is also *enlarged but inverted.*

An interesting feature in connection with real images formed by a concave mirror is that the positions of the object and image are interchangeable and are called **conjugate foci.** If you place the object where the image is, then the image will be formed where the object was previously. It follows from this that if an object

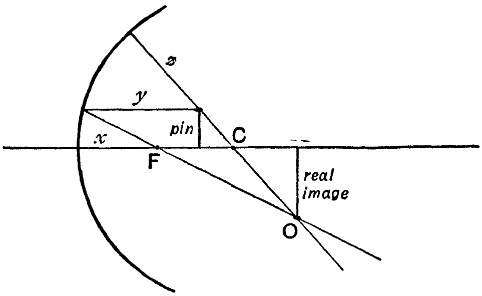


FIG. 211.—THE FORMATION OF A REAL IMAGE BY A CONCAVE MIRROR.

is placed beyond the centre of curvature of a concave mirror, a reduced inverted real image will be formed at a position between the centre and the principal focus. If you possess a concave mirror, verify this for yourself by placing the mirror on a table in such a way that it receives rays from an electric or other light some distance away. When you look at the mirror with your eye in the necessary position you will see a small inverted image of the light floating in the air some inches in front of the mirror. This image can be seen without the use of a screen, and you will appreciate the fact that it is real.

In a **reflecting telescope** the 'object glass' is a large concave mirror which forms an inverted real image of the far distant object, say a star, which is, of course, an immense distance beyond the centre of curvature. In this case the image will be

formed at the principal focus, and an ordinary magnifying lens or eye-piece can then be used to give an enlarged reproduction of the real image.

Owing to the difficulty of making very large glass lenses, modern tendencies are in favour of the large reflector. The larger the aperture or objective of a telescope, whether a glass lens or a mirror, the more light can be grasped by it.

The formula $1/v+1/u=1/f$ can be used in calculations on concave mirrors provided the correct signs are employed. Thus, at what distance must an object be placed in front of a concave mirror of focal length 12 cm. in order to produce an image at a distance of 30 cm.?

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}.$$

In this example,
$$\frac{1}{30}+\frac{1}{u}=\frac{1}{12};$$

therefore
$$\frac{1}{u}=\frac{1}{12}-\frac{1}{30},$$

$$\frac{1}{u}=\frac{1}{20},$$

$$u=20.$$

The object must be placed 20 centimetres in front of the mirror. The image is real, inverted, and its size, determined by the ratio of v to u, is $1\frac{1}{2}$ times that of the object.

Certain kinds of curved mirrors are very useful in cases where a beam of light has to be projected a long way. A **searchlight** apparatus consists of a powerful electric arc lamp, behind which is a curved mirror which throws the light forwards in the form of a powerful beam capable of illuminating objects at a great distance.

We have seen that all rays parallel with the optical axis of a concave mirror pass through the principal focus, F, after they have been reflected. The process can be reversed by *putting a light at the principal focus* and obtaining by reflection a series of

parallel rays of light (Fig. 212). The more accurately parallel these rays are, the farther will they extend without spreading. The advantage of such a parallel beam of light in connection with *railway signal lamps* and searchlights is obvious. But a truly spherical mirror does not produce an accurately parallel beam owing to a defect termed **spherical aberration,** and to produce better results **parabolic** mirrors are used in place of spherical ones. A section through a parabolic mirror gives a curved line called a parabola, instead of an arc of a circle. Spherical aberration may be described as the inability of a spherical mirror to focus accurately at the principal focus all rays parallel with the optical axis, or conversely, the inability to produce a beam of exactly parallel rays when a light is placed in the position of the principal focus.

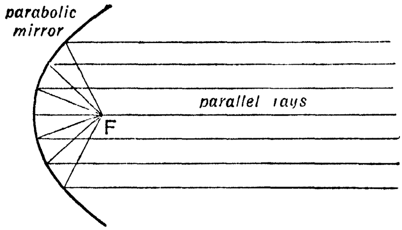


FIG. 212.—THE PRINCIPLE OF A SEARCHLIGHT.

A LIGHT PLACED AT THE PRINCIPAL FOCUS OF A PARABOLIC MIRROR WILL REFLECT A PARALLEL BEAM OF LIGHT.

Radiant heat and waves of sound can be similarly projected as parallel beams by concave reflectors and re-focussed again by a second mirror. The modern beam system of wireless wave-projection is analogous to the projection of parallel beams of light by a searchlight.

CHAPTER XXV

REFRACTION AND ITS PRACTICAL APPLICATIONS

WHEN a ray of light leaves one transparent substance or **medium** and enters another, its direction is altered, and the ray is said to be **refracted.** The amount of this alteration or bending aside depends upon the relative densities of the two media and upon the wave-length of the light ray. The greater the difference in the densities of the two media the greater is the refractive effect. The composite or 'white' light which leaves air and enters a triangular glass prism is all refracted or deviated to one side, but, as we have seen, the violet rays are more refracted than the longer red rays.

The direction in which the light proceeds after it has emerged from one medium into the other depends not only upon the relative densities of the media but also upon the angle at which the rays strike the surface separating the two media. In other words, the shape of a piece of glass or other transparent substance largely determines the direction in which the rays of light proceed after emergence.

This fact is of enormous practical importance. Window panes are composed of sheets of glass having two flat parallel surfaces, so that rays of light, although refracted in passing through the glass, emerge in directions parallel with those at which they entered the glass. Although each ray is slightly shifted to one side by its passage through the window pane, the object viewed, say a house, is seen in front of an observer, as it is in reality. If the window were composed of a wedge-shaped piece of glass wider at one edge than at the other, the house would appear to be shifted considerably to one side of its real position. In this case the object would be viewed through a flat

type of prism and not through a plate or *lamina*, having parallel faces. Dispersion of wave-lengths would also occur, giving a picture of the house with coloured edges. Irregularities in thickness or flaws in the window pane produce distortion, since the rays are there refracted irregularly.

Pieces of glass or other transparent media, such as rock crystal, having curved faces are called **lenses**, and the ways in which these react upon light are described later.

Refraction, due simply to the different densities of two media in contact along a uniformly flat surface, is well illustrated by rays emerging from a pool of water into the air. A stone at the bottom of the pool reflects rays of light, and as each *oblique* ray emerges from the water it is bent more obliquely (Fig. 213). The eye of an observer fails to perceive this alteration in direction to

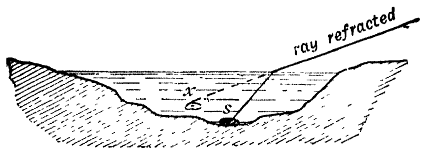


FIG. 213.—REFRACTION CAUSES A POOL TO APPEAR LESS DEEP THAN IT REALLY IS.

the rays ; he is deceived, and to him the stone appears to be in the position x, instead of in its real position s. Not only is the apparent position of the stone shifted to one side, but the water also appears less deep than it really is. If the stone is viewed from a position immediately above it, there is no lateral shifting, but the pool still seems to be shallower than it is because some of the rays reaching the eye emerge from the water at a slight angle, and are refracted. Thus, when trying to pick up a stone from the bottom of a stream, we always have to reach down much farther than we think. A stick when placed in water appears bent for the same reason, the eye being deceived by rays which are really bent aside, but appear to be straight, as indicated by dotted lines in the illustration (Fig. 214). Water and air have very different densities, hence the refractive effect is very marked.

If the path of a ray proceeding from water into air is traced, certain important facts concerning refraction will be understood.

A ray, *se*, emerges at the point *e*, and is refracted along the line *er* (Fig. 215). A vertical line *neo* extends through *e*, and is called a *normal* to the refracting surface, just as lines at right angles to reflecting surfaces are normals. In this case of refraction, the air being less dense than water, the refracted ray *er* is bent further away from the normal. This rule is general; when light rays pass from a denser medium into one less dense they are refracted farther from the normal, and *vice versa*. Now, if at equal distances along *er* and *es*, lines *rn* and *so* are drawn perpendicular to the normal, the relative lengths of these lines depend upon the amount of refraction, and if the length of *so* is expressed as a fraction of that of *rn*, a quantity is obtained called the **refractive index** for water and air. For light passing from water into air the refractive index is $\frac{3}{4}$, and one result of this is that a pool appears to be only $\frac{3}{4}$ of its real depth. If light passes from air into water the refractive index is $\frac{4}{3}$.

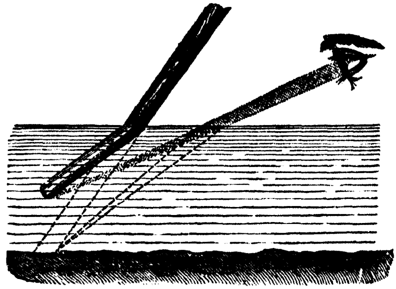


FIG. 214.—REFRACTION CAUSES A STICK IN WATER TO APPEAR BENT.

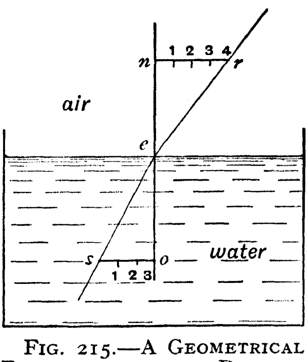


FIG. 215.—A GEOMETRICAL REPRESENTATION OF REFRACTION AND REFRACTIVE INDEX.

A block of ordinary glass acts in much the same way as a pool of water. If a slab of glass about an inch thick is placed on a piece of paper bearing a mark, this mark, which corresponds to the stone at the bottom of a pool, will send light through the glass and into the air. On passing into the air oblique rays are refracted, the eye deceived, and the block of glass appears to be only $\frac{2}{3}$ of its real thickness. The refractive index for light passing from glass to air is $\frac{2}{3}$. These

quantities are constants, the refractive indices always being the same for the same pair of media, and of course the quantities given above are true for light of average wave-length. The refractive index varies slightly with different types of glass.

PRISMS WHICH ACT AS REFLECTORS

In certain circumstances light rays are *reflected* by the surface separating two transparent media, and the effects of refraction can be used to give images similar to those produced by plane mirrors. A few rays proceeding from an object at the bottom of a pool proceed vertically and emerge into the air at right angles to the surface. Such rays pass on without refraction. But most rays pass through the surface obliquely and are bent aside. As shown by Fig. 215, the more oblique a ray is in the water the more oblique is the ray after emergence. Certain rays emerge at such an angle that after refraction they just proceed along the surface of the water. The angle at which such a result is produced is called the **critical angle,** and any rays in the water more oblique than this will not emerge into the air at all; they will be reflected backwards into the water itself, the phenomenon being known as **total internal reflection.** In the case of such reflected rays the surface of the water acts as a plane mirror. A man swimming under water can see only those things out of the water as are situated at a fairly high angle above him. If he glances more obliquely he sees the reflection of objects on the sea floor, provided, of course, the water is not too deep. Similarly, if you visit an aquarium, the surface of the water in the tanks appears as a reflecting surface mostly; only when you are quite close and looking almost vertically can you see through the surface into the air above.

Glass can produce this total reflection, a triangular prism being used for this purpose as a **view finder** in an ordinary hand camera (Fig. 216). Horizontal rays proceeding from the object it is desired to photograph enter an aperture and pass into the glass prism. On reaching the far side of this prism they are totally reflected upwards, and you obtain a view in the top surface of the prism.

Prismatic binoculars or field-glasses make use of the same principle, but since one prism causes lateral inversion as a plane mirror does, the light must pass through another prism which re-inverts the image before it reaches the eye. Thus, in binoculars of this type there are two prisms for each eye, besides lenses which magnify the images. The use of prisms and total reflection enable such field-glasses to give as good a result as would be obtained by a telescope three times their length; there is considerable economy of space. Glass prisms are also employed in the periscope of a submarine. A top prism above the sea reflects light down a telescopic arrangement which magnifies the image of the distant view, and then a second prism reflects the light in a horizontal direction so that the image may be seen by a person in the ordinary upright position.

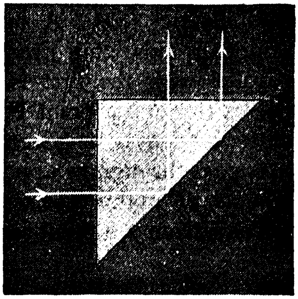


FIG. 216.—TOTAL REFLECTION BY A PRISM USED AS A CAMERA VIEWFINDER.

INSTRUMENTS EMPLOYING A SINGLE CONVEX LENS

If one wishes to see clearly very small writing or marks, a **magnifying glass** is used. This is a **double convex lens,** that is, a thin circular piece of glass having two opposite sides each gently curved and convex or bulging outwards. When such a lens is held in front of, and quite close to, any object, such as printed words on a page of a book, a magnified image of the words is seen, this image appearing at a position behind the lens.

As the lens is moved slowly away from the object, the image becomes larger and larger, but suddenly disappears when the lens is at a certain distance from the object. At a distance greater than this no image is seen.

In order to understand how this image is formed we must trace some of the rays by which it is produced. In the illustration (Fig. 217) the line $eOpx$ at right angles to the central

portion of the lens is called the **principal optical axis,** and the point O at the centre of the lens is known as the **optical centre.** If *pq* is an object, say a pin, the rays proceed from this to and through the lens. A ray of light *p* O *e* coincides with the principal axis and proceeds straight on, while another, *qr*, parallel with the first is refracted, so that after refraction it passes through a point F, called the **principal focus** of the lens, and with lenses in general, all rays parallel with the principal axis pass through or appear to pass through the principal focus. The ray *r*F in this case actually does pass through F, but *appears* to come from *y*, a point some distance behind the object. From *q*

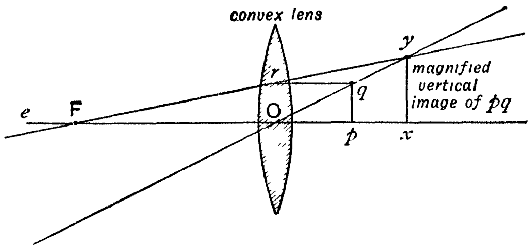


FIG. 217.—A CONVEX LENS FUNCTIONING AS A MAGNIFYING GLASS.

another ray, *q* O, passes through the optical centre and proceeds straight on without deviation, as is the case with all rays which pass through the optical centre. This ray, *q* O, also appears to come from *y*, hence *y* is the position of the upper end of the image *xy*. *This image is magnified, upright, and virtual*—that is, it cannot be caught on a screen—since it appears to be there though the rays themselves do not go there, because they proceed in the other direction.

If the same lens is used as a burning glass, further information concerning images formed by it may be obtained. The sun's rays passing through the lens are focused to one spot on a piece of paper when the latter is at the correct distance. The rays being parallel with the principal axis are all focused to the point called the principal focus, and the distance of this from the lens is called the **focal length** of the lens. Hence to find the focal length, *f*, of a convex lens, focus the sun's rays accurately to a

small spot upon a piece of paper and measure the distance. When you have thus found the focal length of your lens, again use it as a magnifying glass and vary the distance of the object. You will find that in order to obtain an upright virtual image, the object must not be placed at too great a distance, in fact *the lens functions as a magnifying glass only when an object is at a distance less than the focal length.*

But what happens when an object is placed at a distance greater than the focal length? In order to test this it is better to use a lighted candle and do the experiment in a darkened room. Arrange the candle about two inches beyond the focal length and hold a screen of white paper at various distances along

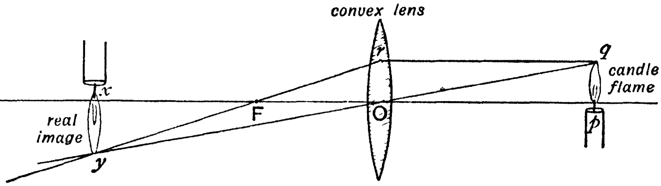


FIG. 218.—THE FORMATION OF A REAL IMAGE BY A CONVEX LENS.

the principal axis, but on the other side of the lens. At one place a clearly defined inverted image is focused on the screen. Since the rays actually converge there, the image is *real*, also it is magnified. The formation of this real image can be explained geometrically by drawing some rays which, being parallel with the principal axis, pass through the principal focus, and others which pass through the optical centre and proceed without deviation (Fig. 218). The lettering on the illustration being similar to that of the previous case a comparison is easy, and it will be noted that the real image is due to the actual convergence of the rays at *y* beyond the lens, instead of an apparent convergence behind it. The **optical projection lantern** and the **cinematograph** operate in this way. An illuminated slide or film is placed at such a distance from a convex lens that a real magnified image is projected upon a screen. As images are inverted, the slide must be placed upside down in order to obtain a picture the right way up.

There is a third case in connection with this sort of lens. Arrange the lens at a distance of several feet from the candle, and you will obtain a real inverted and smaller image on the screen when the latter is fairly near the lens. This third case is of great importance, since it explains the way in which a camera, the eye, and a simple telescope construct images. A **photographic camera** is a light-tight box having a convex lens in front and an arrangement for holding a sensitive plate or film at the back (Fig. 219). Usually there is some arrangement for varying the distance of the lens from the plate, so that a clear or focused image is obtained on the latter. In the camera a convex lens produces a small real and inverted image of an

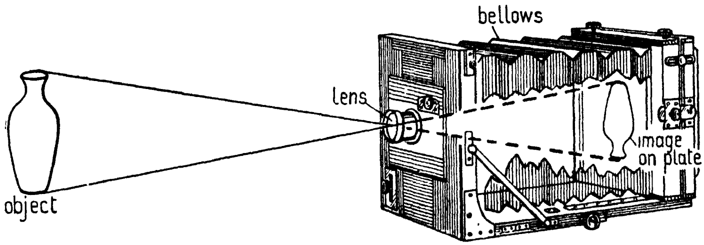


FIG. 219.—THE PRINCIPLE OF THE CAMERA.

object situated at a distance much greater than the focal length of the lens.

The correct distance between the lens and the screen at the back is adjusted by expansion or contraction of the bellows or concertina-like part of the apparatus. In order to obtain a clearly defined image only the middle portion of the lens is used, the outer parts, which would produce a certain amount of indistinctness, being covered by an adjustable diaphragm called a 'stop.' By turning a projecting rim the diaphragm is opened or closed as the case may be. This part of the apparatus bears the symbols $f/5{\cdot}6$, $f/8$, $f/11{\cdot}3$, etc., and these refer to fractions of the focal length of the lens. Thus, with the stop at $f/8$ the diameter of the aperture is equal to one eighth of the focal length, and so on, and there is a definite relation between the amount of light passed into the camera and the focal length of the lens. By this

means both the definition and intensity of light are properly adjusted.

The correct focus or position of the lens having been found, a sensitive plate is put in place of the screen, and the photograph obtained by releasing the shutter for an instant. The plate itself is a piece of glass (or gelatine in films) covered with a thin layer of chemicals containing silver compounds, which are affected by the ultra-violet rays accompanying light waves. In general, light coloured and bright objects reflect more of these rays than dark objects, but colours differ considerably in the amount of reflection they give; for example, red reflects very little and comes out dark on the photo. Consequently the ordinary photographic plate does not reproduce accurately degrees of light and shade corresponding to colours occurring in the object itself **Pan-chromatic plates** specially prepared to respond to various colours give better results, the light and dark portions of the photograph being more in accordance with colours in the original.

Problems on the relative distances of objects and images produced by lenses can be solved algebraically by using the formula $1/v - 1/u = 1/f$ (compare the formula for mirrors). As before, v = the distance of the image, u = distance of the object, and f = the focal length of the lens. The usual convention regarding signs must be observed, and all distances are measured from O, the optical centre. One example will suffice. An object is situated six feet from the lens of a camera, and the focal length is eight inches. How far from the lens must the plate be placed in order to obtain a clear image? As the focal length is given in inches, other quantities must be in the same units.

$$\text{Now} \qquad \frac{1}{v}-\frac{1}{u}=\frac{1}{f}, \quad \text{hence } \frac{1}{v}-\frac{1}{72}=\frac{1}{-8};$$

$$\therefore \frac{1}{v}-\frac{1}{-8}=\frac{1}{72}; \quad \therefore v=\frac{-8}{72}; \quad \therefore v=-9.$$

The distance of the plate from the lens must be 9 inches.

Many small hand cameras have no means of focal adjustment, the films being placed at a definite distance behind the lens.

In such cases this distance equals the focal length of the lens, and it is assumed that objects photographed will generally be at such distances that their images are formed at the principal focus. Rays from an infinite distance are parallel and are focused at the principal focus, and in photography an object at twenty or thirty feet is far enough from a hand camera for the rays to be regarded as parallel.

THE HUMAN EYE

The **eye** is in structure and mode of working very similar to a camera (Fig. 220). Here again there is a light-tight box, a lens in front and a sensitive screen at the back. The main chamber of the eye is a dark box, which retains its shape because it is filled

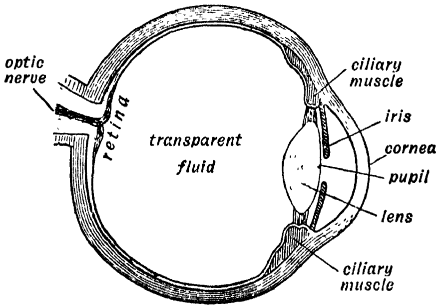


FIG. 220.—HORIZONTAL SECTION THROUGH THE HUMAN EYE.

with a transparent fluid. At the front of this chamber is the lens which focuses light rays so that small real images are formed on a sensitive nervous screen called the **retina** at the back of the eye. In front of the lens is an adaptable structure similar to the diaphragm of a camera and performing a similar function, namely, the regulation of light passing through the centre of the lens. This diaphragm or **iris** is the coloured portion of the eye, and the central spot, appearing black because it lets the light through and reflects none, is called the **pupil**. In front of the lens and iris is another smaller chamber filled with a clear transparent fluid covered by the front transparent wall called the **cornea.**

The eye acts in a manner similar to that of a camera supplied with accurate focusing devices. It is not like a small hand camera; if it were we should not see clearly objects placed close to us. But how does the eye adapt itself so that an image is always formed on the retina at the back when the distances of external objects are so varied? The retina remains fixed in position, but the lens itself is composed of soft material, the surfaces of which can be made more convex or less convex as required. These changes in curvature alter the focal length of course, and the shape of the lens is controlled by the **ciliary muscles.** This adaptation of the lens to suit the different distances of external objects is called **accommodation.** The sensations produced on the retina by images are conveyed to the brain by the **optic nerves.** Real images formed by lenses are always inverted, but we do not see objects upside down: *the brain inverts the picture.* This is a case of psychological or mental accommodation.

Now, this mental accommodation remains good throughout life, but that of the eye itself may not do so. Many middle-aged and elderly persons and some children have eyes in which the dark box or posterior large chamber of the eye is either too long or too short. If this is too long (Fig. 221 A), the image formed by the lens falls short of the retina, and the person is said to be **short-sighted.** This defect can be rectified by the use of a concave or diverging lens placed in front of the eye. In **long-sight** the image is formed at too great a distance; it passes beyond the retina (Fig. 221 B), and this can be remedied by placing an additional *convex* lens in front of the eye. Some eyes are irregularly shaped, so that vertical objects are seen clearly though horizontal objects at the same distance are indistinct, or *vice versa.* This defect is known

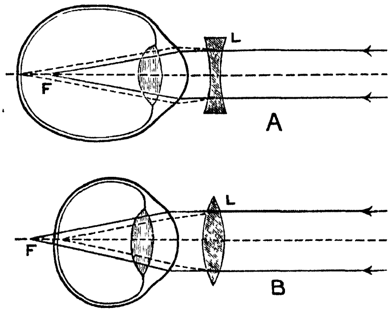


FIG. 221.—EXPLANATION OF SHORT SIGHT (A) AND LONG SIGHT (B).

as **astigmatism** and requires special lenses made according to the prescription of a skilled oculist.

One other point concerning vision must not be overlooked. Objects appear *solid*, that is, having thickness as well as length and breadth, because we have two eyes, and one eye does not see an object from exactly the same view-point as the other. The two pictures are slightly different, but their combined **stereoscopic** effect produces the idea of solidity. A similar effect can be produced in photographs if two photos of the same thing are taken from slightly different positions as if seen separately by the two eyes. These photographs are then mounted side by side and viewed together by the observer looking through two separate magnifying eye-pieces, one for each eye. Provided the photo which should be on the left side is on the left and the other on the right, the objects seen in the photograph appear solid and the arrangement is called a stereoscope. The application of this principle to the cinematograph would give very realistic pictures but would be difficult and very expensive.

TELESCOPES AND MICROSCOPES

A simple **refracting astronomical telescope** is an arrangement for obtaining a view of distant objects. Two convex lenses are mounted in tubes, so that by sliding one tube within the other

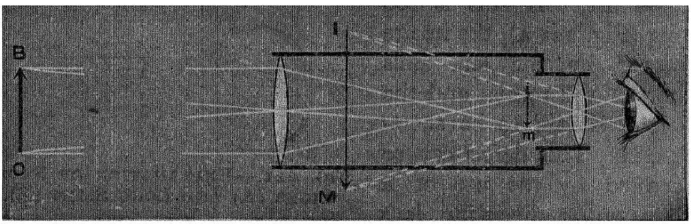


FIG. 222.—THE PRINCIPLE OF AN ASTRONOMICAL TELESCOPE.

the distance between the lenses can be adjusted and the images thereby focused correctly (Fig. 222). The lens at the larger end of the telescope is called the **object glass**, and since rays proceeding from an object at a great distance are parallel, a real

image of this object is formed at the principal focus. The other lens or **eye-piece** is then brought near this real image, so that a magnified virtual image (IM) of it is seen. Since the real image is inverted, this virtual image is also upside down, a fact of little consequence in astronomical work, but one that does matter when terrestrial objects are viewed by such persons as surveyors and sailors. In a **terrestrial telescope** the real image formed by the object glass is re-inverted by another convex lens before it is magnified by the eye-piece.

Opera glasses (Fig. 223), for use at theatres, and ordinary field-glasses which do not make use of total reflection by prisms, are rather different from the ordinary telescope. They are binocular,

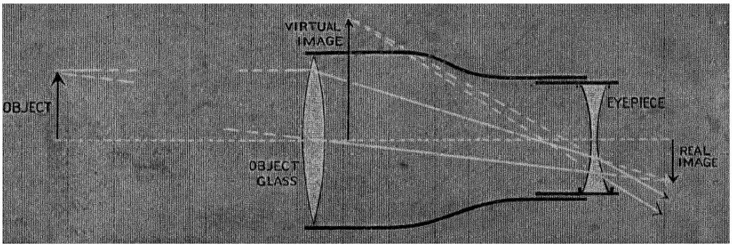


FIG. 223.—THE PRINCIPLE OF THE OPERA GLASS.

so that both eyes can be used, but apart from this the formation of images is not quite the same. As in a telescope, a convex lens produces a real image, but the rays which produce this image are intercepted and caused to diverge by a double concave lens forming the eye-piece. The image actually seen is virtual, magnified, and re-inverted, this last feature constituting the chief advantage of this class of instrument. The magnification is not so good as that obtained with an ordinary telescope, but is sufficient for viewing a stage or a horse race. This is the class of telescope invented by **Galileo** and used by him in his observations on the moons of Jupiter.

A **microscope** is an arrangement of lenses used for viewing extremely small objects, and resembles a telescope in having the lenses mounted in metal tubes (Fig. 224).

In a microscope an **objective** or convex lens of very short focal length is used to produce a magnified real image of the minute object. This case is similar to the production of an enlarged real image by an optical projection lantern, and with either instrument the object must be placed at a distance from the lens slightly longer than the focal length. The real inverted image formed within the barrel of the microscope is again magnified by another convex lens, the **eye-piece**, which produces a virtual image which remains upside down.

Greater magnification can be obtained by using another objective having a shorter focal length, but of course, this objec-

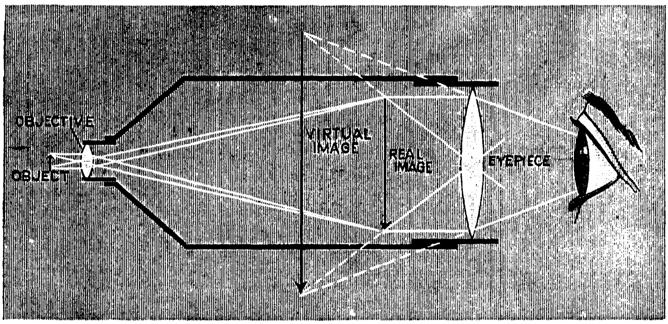


FIG. 224.—A COMPOUND MICROSCOPE.

tive must then be brought nearer to the object. An ordinary low-power objective commonly used in biological or other work has a focal length of about one inch, and magnifies an object so that its *length* appears about twenty-five times as long as it really is. A high-power objective gives a linear magnification about 100 times the original size.

If either the eye-piece or objective of a microscope is examined, it is found that it consists of not merely one lens, but a combination of lenses. The image obtained by a single lens is not so accurate as it should be, because the light is dispersed into the colours of the spectrum.

Produce on a piece of white paper a real image of a candle flame formed by an ordinary convex lens. If the paper is

moved slightly backwards and forwards it is seen that the edge or boundary of the image is coloured, violet when it is nearer the lens, and red when it is a little farther from the lens. This is what one should expect, since violet rays are refracted more than red rays. The formation of these coloured images by single lenses is called **chromatic aberration** (Fig. 225 (i)), and the combination of lenses in an eye-piece or objective is a device for the prevention of such aberration. An **achromatic lens,** as used in good microscopes and telescopes, consists of a convex lens composed of crown glass placed against a concave lens

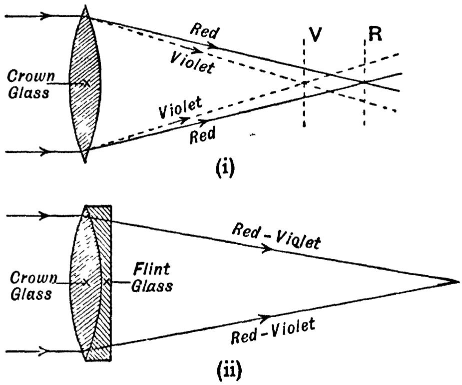


FIG. 225.—A SIMPLE LENS AND AN ACHROMATIC LENS.
IN AN ACHROMATIC LENS ALL COLOURS ARE FOCUSED AT THE SAME PLACE.

composed of denser flint glass (Fig. 225 (ii)). In such a combination the dispersion by one lens neutralises that of the other, though the arrangement *as a whole* still functions as a converging or convex lens, the focal length of the convex portion being shorter than that of the concave part.

Lenses are useful in other ways besides the formation of images. As in the case of a parabolic mirror, if a source of light is placed at the focal point a beam of parallel light can be obtained, but of course the light passes through the lens and is not reflected by it. The practical application of this is of great importance in cases where it is desired to project a beam of light in any direction and not merely in one direction. The

best known example is a lighthouse, where a beam of gently diverging light is first flashed one way then in another direction. As very large lenses are extremely difficult to make, heavy, and very costly, the light is passed through an arrangement composed of many glass prisms or dioptric lenses which give the desired result (Fig. 201). The apparatus is rotated so that the beams sweep round the horizon and appear in any given direction at regularly timed intervals.

Mast-head lamps and others on ships are similarly fitted with dioptric lenses so that the beams diverge slowly and are seen in many directions.

CHAPTER XXVI

SOUND AND MUSIC

THE sense of hearing is a psychological or mental effect resulting from a physical cause. We perceive a sound, whether it is harsh and noisy or pleasant and musical, because some external cause makes impressions upon the nerves of our ears. The external causes which produce in our brains the sensations we call sounds are varieties of wave motion occurring in matter—air, water, metals or other substances as the case may be. We have seen that light which may produce the sensation called sight consists of wave motions in ether, not in ordinary matter, thus differing greatly from sound. If an alarum clock is placed under a glass bell jar over an air pump, and the air removed, the vibrating alarum makes no noise though the hammer is seen in motion. Ether occupying the vacuum transmits light, but there is no air or other material substance to transmit sound waves.

The transmitting media being so very different in the two cases, it is not surprising that resulting features such as wave-length and velocity are also very dissimilar. Light waves are only millionths of an inch in length, but travel at the enormous speed of 186,326 miles per second, whereas sound waves traversing air may be measured in feet though they only proceed at a velocity of some 1100 feet in one second. The velocity of light has been accurately determined by several independent methods, one of the most recent being that of Professor Michelson of Chicago, who caused light to be sent from one mountain to another at a distance of 22 miles away. A fixed mirror on the second mountain reflected the light back to the first, and the interval of time taken by the light to perform the double journey of 44 miles was carefully measured by means of suitable apparatus.

The velocity of sound has been determined in a very similar way by noting the interval of time taken by a sound wave in traversing a definite number of miles. When a gun at a certain locality is fired, observers at a distant place see the flash and commence to count the interval of time which elapses before the sound is heard. The velocity of light by which the flash is seen is so great that the time taken by it, a very minute fraction of a second, can be ignored when the speed of the incomparably slower sound is to be determined.

Sound waves travel through various material substances or media at different velocities, but we must first consider the nature of the waves which constitute sound itself. In most cases the transmitting medium surrounding the ear is air, and practically all sounds, pleasant and otherwise, are transmitted by this medium, hence the nature of sound waves in air are of particular interest. Waves of the sea and light waves in ether are transverse, that is, the oscillations take place in a direction at right angles to that in which the wave motion itself travels. But sound waves in air are *longitudinal*, the particles move backwards and forwards in the *same* direction as that along which the wave motion proceeds. When air particles are pushed forwards or compressed a condensation occurs at one place and a rarefaction at another place (Fig. 226). Then because the air is elastic the particles return, but overshoot the mark, producing a rarefaction where before there was a condensation. These forward and backward oscillations are communicated from one set of air particles to the next set, and so on, the alternating compression and rarefaction thus constituting a type of wave motion which proceeds outwards in all directions from the disturbance that produces it.

The rapid to and fro motions of a tuning fork impart wave motion to the air and are an example of a *regular* disturbance producing a musical note, while the blows of a sledge hammer may serve to illustrate the kind of cause which produces an *irregular* disturbance resulting in the sensation called a noise. In either case longitudinal waves consisting of alternating compressions and rarefactions pass through the air and reach the ear, but those due to the tuning-fork are properly timed and regular in form, whereas those produced by the sledge hammer are badly

timed and irregular. But whether they produce musical notes or irregular noises the wave motions travel through the air with the same speed, the actual value of which depends upon the temperature and density of the air at the time. *When the air is of average density and its temperature is 0° C. the velocity of sound waves through it is* 1088 *feet per second*, and this rate increases by about 2 feet for every additional degree Centigrade, since warm air is less dense than cold air, and the speed of sound in gas is increased by a decrease of density.

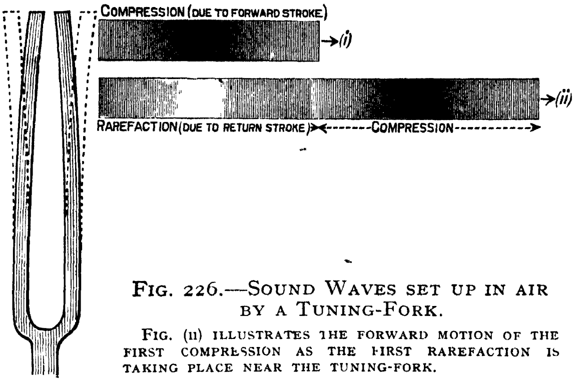


FIG. 226.—SOUND WAVES SET UP IN AIR BY A TUNING-FORK.

FIG. (II) ILLUSTRATES THE FORWARD MOTION OF THE FIRST COMPRESSION AS THE FIRST RAREFACTION IS TAKING PLACE NEAR THE TUNING-FORK.

During a thunderstorm on a warm summer day the air temperature is such that the noise of thunder travels about 1120 feet per second, hence the actual distance of the lightning from an observer can be found by a simple calculation. When the lightning is seen at the same moment as the thunder is heard, the electric discharge is dangerously near, only a few hundred yards overhead. In a denser gas, such as carbon dioxide, the velocity of sound is less than it is in air, but in hydrogen or other light gases and in air rendered less dense by the presence of much water vapour the velocity is greater.

Sound waves in liquids and solids are also longitudinal in nature, but they proceed at very much greater speed than in a gas. In water the velocity is more than four times as great as it is in air, and the loss of energy is less, facts which explain why the sound of the paddles of a steam-boat are

heard even when the ship is at a great distance from land. In rigid solids, particularly in metallic rods and wires, sound waves travel at a greater speed still; for example, in steel its velocity is more than 16,000 feet per second. The approach of a distant tramcar can be perceived long before it comes in sight if an ear is placed against one of the posts supporting the overhead wires conveying the electric current. These wires and posts conduct the sound much more quickly and with less loss of energy than the surrounding air does.

ECHOES AND THE HYDROPHONE

Mirrors reflect light, a breakwater reflects sea waves, and many objects, such as walls, high buildings, and hills, send back sound waves which strike them. The reverberating nature of thunder is due to repeated reflections of sound by clouds. Actually, one flash of lightning is accompanied by one original sound. When a person situated at a sufficient distance from a cliff shouts, the noise is heard again after a slight interval of time, the **echo** or second noise being due to the reflected sound wave reaching the ear. If the cliff is too close, the ear is unable to separate the original sound from the echo, their perception is simultaneous. *In air this necessary minimum distance is about* 110 *feet.* When a cliff or hill is at too great a distance the returning sound waves are so weakened that they do not produce any audible effect. If rays of light or waves of sound are to remain strong over considerable distances they must be projected as parallel beams, and not be permitted to spread outwards in all directions. A parallel beam of light is projected by a searchlight, and with suitable apparatus a parallel beam of sound can also be projected. The reflection of such a sound beam by an iceberg or hidden rocks can be utilised to determine the direction and distance of such submerged objects, provided a sensitive apparatus is used to detect the return of the sound waves.

An apparatus for the detection of the sound waves traversing water is called a **hydrophone** (Fig. 227), and consists of a disc which, vibrating under the influence of sound waves, operates a microphone and thus produces audible effects in attached

telephones (Microphone, Chapter XXVII). Only one side of the hydrophone is exposed to the action of sound waves, hence the direction of sounds received is clearly indicated. During the Great War this instrument was much used for the detection of enemy submarines, which of course created their own sounds.

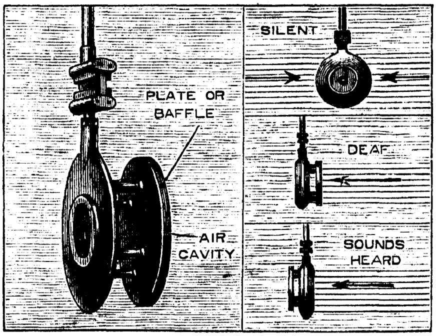


FIG. 227.—THE HYDROPHONE

FOR DETECTING SOUND WAVES BENEATH THE SURFACE OF THE SEA. THE USE OF A BAFFLE PLATE ENSURES THAT SOUNDS ARE HEARD ONLY IN ONE DIRECTION.

If sound waves are permitted to spread they become weakened, and the converse is true; sound over a larger area can be concentrated to a smaller area, thus producing a magnified effect at the point of concentration. This is the principle of the **ear trumpet** used by deaf persons. In speaking tubes and in a physician's **stethoscope** sounds are conserved within the tube, while in a **megaphone** sound waves are projected in such a way that they spread slowly, hence they can be heard at some distance.

PITCH AND FREQUENCY

Though sound waves are longitudinal they have definite wave-lengths and frequencies. *The wave-length is the distance between two consecutive positions of maximum compression, or, of course, that between two consecutive positions of maximum rarefactions.* The frequency is the number of waves or oscillations per second, and, as in the case of light, the wave-length multiplied by the frequency is equal to the velocity or distance

per second that the sound travels. For example, if the velocity is 1125 feet per second and the wave-length is $4\frac{1}{2}$ feet, then the frequency is 250.

When the wave-lengths are relatively large and the frequency correspondingly small, low musical notes or noises are heard. The lowest notes produced by an average piano have a frequency of about 30, and waves of considerably lower frequency exist but are not all heard as sound. Similarly, frequencies which are too great are not audible, since the ear can perceive only frequencies within certain limits, roughly from 16 to 16,000 per second. A low bass note is said to have a low **pitch**, a high treble note a high pitch, and so on; hence *the pitch of any note is determined by the frequency*. The loudness or intensity of any note or noise is not the same thing as pitch, and is not the result of frequency, but is determined by **amplitude**, or the degree of compression and rarefaction irrespective of wave-length.

There are many everyday examples of the influence of frequency upon the pitch of a note. A circular saw gives a higher note if its speed of rotation is increased, similarly with the toothed wheels in the gear box of a motor car, the rotating parts of machinery, the wheels of a railway carriage, and so on. The high pitched piping note accompanying the flight of a mosquito is caused by the extremely rapid beats of the wings, some hundreds per second; in fact the note emitted by an insect in flight is a fairly good indication of the rapidity with which the wings vibrate.

When any arrangement producing a note of definite pitch is quickly rushed towards or away from a hearer, the pitch appears to rise or fall because the wave-length shortens slightly as the object approaches and lengthens as it recedes. This means that an increase of frequency with higher apparent pitch occurs on approach, and a decrease in frequency with an apparent lower pitch on receding. The whistle of an express locomotive illustrates this principle. It should be realised that in reality the pitch of the whistle itself remains constant; it is the *frequency of the waves reaching the ear* that is increased or diminished.

That it is the frequency which determines the pitch of a note can be shown by means of an apparatus called a **siren**. There

are various forms of such apparatus, a simple kind consisting of a disc pierced by a number of holes (Fig. 228). If a stream of air is directed against these holes as the disc is rotated, a note is obtained and the pitch depends upon the number of holes the air encounters in a second. By causing the disc to rotate at a greater speed, a higher note is produced. Some sirens used on ships are based upon this principle, though many are merely enlarged tin whistles operated by blasts of steam. The note obtained from a disc siren is due to regularly timed puffs of air passing through the holes and causing compressions in the external air. In such an apparatus used for actual measurement of frequency there are dials which register the number of revolutions of the disc. This number multiplied by the number of holes gives the frequency, and it is obvious that the frequency of another instrument, say a tuning-fork, can be determined by the adjustment of the siren to give the same note as the tuning-fork.

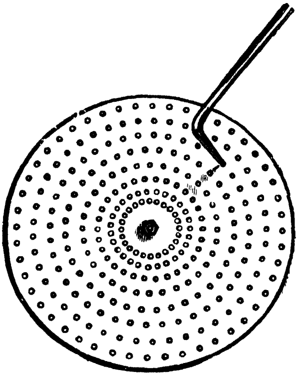


FIG. 228.—A DISC SIREN.

THE MUSICAL SCALE AND THE PIANO

Physically, music is concerned with the production of notes and of simultaneous groups of notes, the combined frequencies of which produce pleasant or harmonious sounds. Psychologically, music is much more than this since it is the expression of emotion or ‘ feeling ’ in addition to the production of sounds which are merely harmonious. Technique alone does not produce a Kreissler or a Mendelssohn.

The origin of music must be traced to the attempts of primitive man to express his feelings by means of sounds. The most ancient of all musical instruments is undoubtedly the human voice, and the earliest types of concerted music were probably in the nature of war cries and folk songs. Later, it was dis-

covered that notes could be produced by beating objects and by blowing air through pipes. The evolution of the earlier types of musical instruments is a matter largely wrapped in obscurity, such knowledge as we possess being obtained from old mural decorations and the discovery of actual instruments and models. Wind instruments similar to the flute and primitive reeds of the shepherd's pipe type were used in Egypt thousands of years ago. Ancient models of the *Hydraulus*, or water organ, show that the Romans possessed organs in which the air necessary to operate the pipes was maintained under pressure by means of water, and admitted to the pipes by means of keys on a keyboard. Pictures on stone slabs obtained at Nineveh prove that the dulcimer, the remote ancestor of the piano, was used by the Assyrians more than a thousand years before the time of Christ. Hand hammers were employed with the dulcimer, keys being intro duced during the middle ages in the clavichord, improved in the harpsichord, and more or less perfected in the piano, the earliest types of which appear to have been introduced about the year 1700 A.D. Violins, which developed from viols, attained the greatest degree of perfection at that time when **Stradivari**, then in his prime, and **Guarneri of Cremona**, described as the 'Michael Angelo of fiddle makers,' produced instruments that are rarely equalled at the present time.

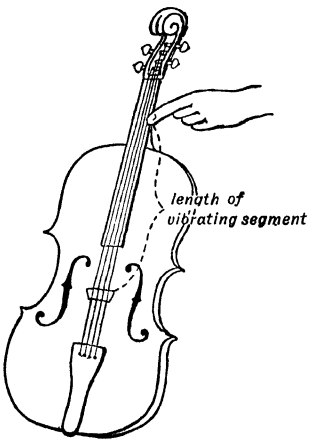


FIG. 229.

IN INSTRUMENTS OF THE VIOLIN CLASS THE LENGTH OF VIBRATING SEGMENTS CAN BE ADJUSTED BY MEANS OF THE FINGERS, HENCE FEW STRINGS GIVE MANY NOTES. IN A PIANO EACH STRING IS OF FIXED LENGTH AND GIVES ONLY ONE NOTE.

The relations of various musical notes to one another can be understood by reference to a piano, an instrument consisting of many stretched steel wires, each wire being struck by a hammer so that it vibrates and gives out a note when required.

In the musical scale there are seven notes, and these in their usual order are named respectively *C*, *D*, *E*, *F*, *G*, *A* and *B*. Each

note has a definite frequency in any given system of pitch. When a piano or other instrument is tuned to the **French normal diapason pitch,** the system in common use, the frequencies of the middle white notes from *C* to *B* respectively are 256, 288, 320, 341·3, 384, 426·6, and 480. In the so-called **concert pitch of the Philharmonic Society** the frequencies are a little higher than these; for example, that of middle *A* is 439. Many large organs have pipes of such lengths that the notes produced are of this concert pitch, hence other instruments must be tuned in agreement. At considerable expense certain organs, for example that in the Albert Hall, London, are being altered to give notes of the normal diapason pitch, which is considered better by the majority of musicians. Military bands observe a pitch still higher than that of the Philharmonic Society, the middle *A* having a frequency of 452. Bands playing in the open find that a higher pitch is better, since changes in temperature of the air modify the pitch considerably; this is particularly the case in hot climates, such as that of India.

Though there are these different schemes of pitch, instruments remain in tune *provided the relative frequency of each note is correct with regard to the others.* It is a matter of *ratio*, and the ratios of the frequencies of notes from *C* to *B* inclusive are represented by the numbers 24, 27, 30, 32, 36, 40 and 45.

A 'black' note on a piano has a frequency intermediate between those of the two white notes adjacent to it. Thus a certain black key between *A* and *B* gives a note called either *A* sharp or *B* flat in practice, though theoretically there is a difference between them.

There is quite a large number of white keys on a piano, and any eight notes, say from middle *C* to the next *C* inclusive, constitutes an **octave.** The higher *C* has a frequency just double that of middle *C* at the lower end of the octave. Any one of the seven notes from *C* to *B* has corresponding notes in higher octaves, and the frequencies of these higher notes are multiples of that of the original or **fundamental** note. Similarly the notes in lower octaves have frequencies which are sub-multiples of that of the fundamental. These notes which are either multiples or submultiples of the corresponding middle notes are called **harmonics,**

and, of course, there are many harmonics of one note. Thus middle *C* at a frequency of 256 has, as harmonics, notes of frequencies 512, 1024, and so on up the piano keyboard, and sub-multiples such as 128, 64, and 32 going down the keyboard. It will be observed that these particular frequencies give harmonics *and* octaves of middle *C*, but there are other harmonics, such as the note of frequency 768, which are not octaves. All octaves are harmonics, but all harmonics are not octaves.

Harmonics occur in other forms of wave motion besides sound. In wireless reception a broadcasting station can be received on a wave-length double (frequency half) or half (frequency double) that of its proper wave-length, but reception of these harmonics gives much weaker volume than that obtained when a station is tuned in to its correct fundamental wave-length.

In music, it usually happens that a fundamental note and its harmonics are heard together, the combined result generally producing a very pleasing effect. The *quality* of a note largely depends upon the combination of harmonics and this partly explains the differences of the same notes played upon different instruments, the piano and violin, for example. The sixth harmonic produces a harsh effect, and to prevent the presence of this the hammers of a piano strike the wires at a spot $\frac{1}{7}$th of their length from one end.

Now let us consider the actual mode of sound production by a piano or by any of the so-called stringed instruments. In a piano steel wires struck by hammers produce the sounds, in a violin the strings composed of catgut are caused to vibrate by the friction of a bow, but in either case the underlying principles of note production are the same. In a laboratory the study of sounds produced by stretched wires is made by means of an instrument called a **sonometer** (Fig. 230). This consists of two thin steel wires, stretched above a long hollow wooden sound-board. Two wires are used so that when desired one can be kept constant, the other varied. Both wires are firmly fixed at one end, and the other ends can be tightened either by pegs similar to those of a violin, or by passing the wire over a small wheel and attaching heavy weights. This latter mode is employed when it

is desired to investigate the effects of tension on the vibrating wire. Two fixed 'bridges,' one at either end, fix exactly the maximum length of wire capable of vibration. Movable bridges can be placed at suitable places so that a wire can be divided into two or more vibrating segments.

When one of the wires of a sonometer is tightened and plucked it gives out a certain note called the fundamental. The wire itself vibrates transversely though it originates longitudinal sound waves in air, and it is this resulting wave motion in the air that affects our ears. This fact must not be overlooked, as it explains the action of all stringed instruments; the strings themselves vibrate in a direction at right angles to their length, but the

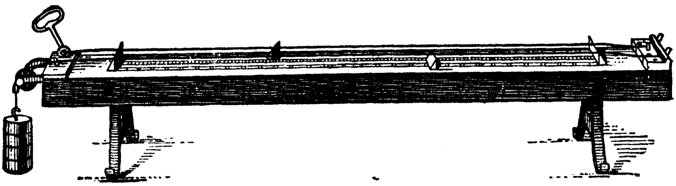


FIG. 230.—A SONOMETER.

air between our ears and the instruments vibrates in the usual longitudinal manner characteristic of sound waves in a gas. By adjusting the tension by weights the wire can be made to give any well-known note, such as middle *C* of the piano.

Now, if a movable bridge is placed exactly at the middle point of the stretched wire, there will be no transverse vibration at this middle point; the wire as a whole is divided into two equal vibrating segments, and the note produced is the **first harmonic** one octave higher than the fundamental. If the bridge is placed at a point $\frac{1}{4}$ of the length of the wire, four vibrating segments are produced and the resulting note is the **second higher octave** of the fundamental note. The points at which there is no transverse motion are called **nodes,** the vibrating parts are **internodes,** and strips of paper will remain at the nodes but are thrown off if placed at positions on the internodes.

Careful experiments with the sonometer show that (1) *the frequency of vibration and consequently the note produced is inversely proportional to the length of wire.* This explains the

use of shorter wires for the higher notes of the piano, and the shortening of a violin string by the finger when a higher note is to be played. (2) *The frequency is proportional to the square root of the tension.* A certain piano note is produced by a wire of given length, and if this note is flat it can be put in tune by increasing the tension. Other stringed instruments are tuned up in the same way. (3) *With wires of given length and tension the frequency is inversely proportional to the weight of the wire.*

It is more convenient to use heavy wires for base notes on a piano than to have them very long or to have a tension very different from that on the other wires. For the same reason the fourth or G string of a violin is loaded with wire.

THE ORGAN AND WIND INSTRUMENTS

A stretched wire fixed at each end exhibits a wave motion that cannot proceed beyond the fixed ends, hence this sort of motion is frequently called **transverse stationary undulation.** A column of air in an organ pipe affords an example of stationary *longitudinal* vibration. The effect of such a vibrating air column can be observed if a tuning-fork is held over the mouth of a tall glass cylinder containing air (Fig. 231). When a certain quantity of water is poured into the jar the length of the air column is so adjusted that it vibrates in time with the tuning-fork and the note is considerably reinforced. The air vibrating in sympathy with the tuning-fork is said to **resound,** and the note produced is an example of **resonance.** This resonant effect will be produced only when the air column is of the correct length for the note given by the fork.

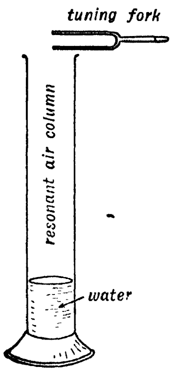


FIG. 231.—REINFORCEMENT OF A NOTE BY AN AIR COLUMN.

In an organ pipe the air is caused to vibrate by a different means. An organ consists of a collection of wooden and metal pipes, of various sizes, the whole instrument resembling, in many ways, a set of tin whistles. Air is forced through an opening

at the end of each pipe and directed against the edge of an aperture at the side (Fig. 232). This throws the whole air column into stationary undulation and the length of the pipe determines the frequency of the reinforced note. If the pipe is closed at the further end, the wave-length is *four* times that of the pipe, but if it is open, the wave-length is *twice* that of the pipe. It is evident that an open pipe has a frequency twice as great as that of a closed pipe, and gives a higher note, and of course shorter pipes give higher notes than longer pipes of the same type. The keys on the manual of an organ simply release the air so that it enters the corresponding pipes.

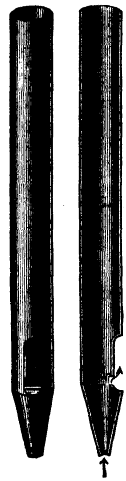


FIG. 232.—ORGAN PIPES.
FRONT VIEW AND SIDE VIEW OF VERTICAL SECTION.

A tin whistle resembles an organ pipe in its mode of sound production, a blast of air being directed against a thin edge at an aperture in the side of the tube. But it differs from an organ pipe in having six holes in the side. The wave-lengths, hence the frequencies and notes, are produced by removing the fingers from the holes, since *an open hole determines the end of the resonant column of air.* The vibrating air column extends from the aperture near the mouth down as far as the first uncovered hole. Wave-lengths and frequencies are similarly adjusted for various notes in some other wind instruments.

In cases like the **clarinet, oboe,** and **bassoon** a vibrating tongue-like structure called a **reed** is employed to throw the air column into resonant vibration, hence these are known as reed instruments (Fig. 233). The human voice is the result of vibration of two membranes or **vocal chords** stretched across the part of the throat called the **larynx.** A narrow gap between the chords permits air to pass, and the note obtained depends partly upon the force of the air and partly upon the tension on the chords. In childhood these chords are relatively short so that the voice is of higher pitch than that of an adult.

Certain modern appliances provide us with second-hand speech and music, the most popular of these forms of apparatus being the **gramophone.** In this, a steel needle moves under the influence of irregularities in the surface of a circular black disc commonly known as a 'record.' The irregularities correspond to the original sound vibrations that impressed their wave forms upon a soft wax disc at the time the actual performance of speech or music was taking place. The wax is covered with metal by an electrolytic process (see Chapter XXVIII), and a die is thus obtained by means of which accurate copies can be stamped upon

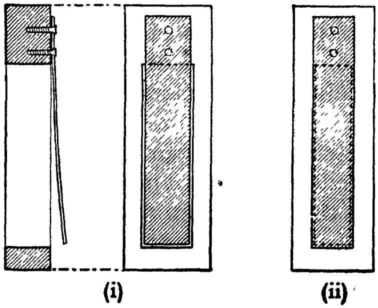


FIG. 233.—VIBRATING REEDS.

(i) SIDE AND FRONT VIEW OF A 'FREE' REED AS USED IN A CONCERTINA AND 'MOUTH' ORGAN. (ii) A 'BEATING' REED IN WHICH THE REED IS LARGER THAN THE OPENING BEHIND IT. SOME ORGAN PIPES HAVE REEDS OF THIS TYPE.

the black records sold to the public. The movements of the steel needle are communicated to a mica disc within the sound box of the gramophone and the motions of this disc faithfully reproduce the original sounds. In many modern hornless types of instrument the sounds are reinforced by the resonance of air in a cabinet.

In a telephone, sounds are reproduced by electro-magnetic means, as described in the next chapter.

THE EAR

The organ by means of which we perceive sounds occurring in the external world is both delicate and complex. The human ear consists of three main parts. The **outer ear** consists of a flap

communicating with a relatively wide passage or tube, the arrangement functioning as a collector of sounds. The middle ear or **tympanum,** commonly called the **drum,** is a body containing three little bones capable of being thrown into vibration

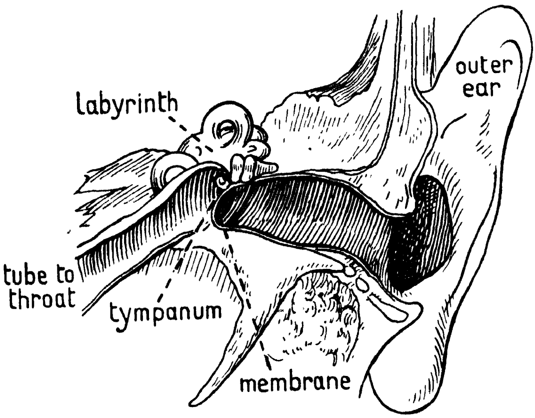


FIG. 234.—SECTION THROUGH THE HUMAN EAR.

by sound waves entering the outer ear. In order that conscious sensations corresponding to these vibrations may be perceived by the brain a system of nerves is necessary, and these are situated in the inner ear or **labyrinth,** so called on account of its complex structure.

CHAPTER XXVII

MAGNETISM AND ITS RELATION TO ELECTRICITY

NATURAL AND ARTIFICIAL MAGNETS

THE name magnet is derived from Magnesia in Asia Minor, where, at a very early date, it was observed that certain specimens of a mineral oxide of iron, now known as **magnetite**, possessed the power of attracting pieces of iron. Magnetite is a black mineral occurring extensively in Sweden, Spain, and North America, but it is not always magnetic. Specimens possessing

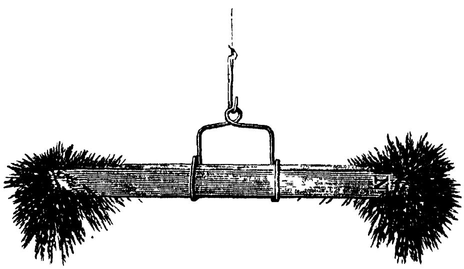


FIG. 235. IRON FILINGS ADHERING TO THE POLES OF A BAR MAGNET.

magnetic properties are known as **lodestone** (*i.e.* leading stone), and if one of these is placed in a heap of iron filings and then withdrawn, clusters of filings adhere to the lodestone, particularly at two opposite parts commonly called **poles**. A small bar magnet behaves in a similar way when placed in iron filings (Fig. 235). Hardly any filings adhere to the middle part of the bar, though large numbers are clustered around the two ends near which the poles are situated.

The magnetic force of attraction appears to be more concentrated at these poles or positions near the ends, but it is more correct to say that the magnetism near the centre of the bar is not *free* to exert an influence on outside objects as it is in the region of the poles. By comparison of the number of small nails or tacks which can be supported by the middle of a bar magnet with the number supported at other parts of the magnet, it is possible to form some idea of the distribution of free magnetism in the magnet as a whole.

If a magnet is fairly large and in good condition the filings or tacks may jump to the magnet, thus illustrating the fact that magnetism is a force which acts across apparently empty spaces, and in this it resembles gravitation. But magnetism differs from gravitation in exerting an appreciable force only upon certain substances, chiefly iron and steel ; moreover, in certain cases the force is one of repulsion, endeavouring to push or repel steel objects away from the magnet instead of attracting it. Gravitation is always a force of attraction, and all objects are influenced by it, though in different degrees of intensity according to their joint masses and distances apart.

The forces exerted by a magnet are connected with the way in which the molecules or minute particles of the substance are arranged within the bar, and this can be shown by placing some steel filings inside a glass tube and by magnetising the filings by a simple stroking process (Fig. 236). The experiment also shows that magnetic influence passes through glass. Bring down one end or pole of a bar magnet upon one end of the tube, then slide the magnetic pole along the tube as indicated by the arrow in the figure. Next raise the magnet away from the tube, bring the same pole down again on the glass tube at the end where you began the first stroke and repeat. When this is done several times the influence of the magnetic pole causes the filings in the tube to arrange themselves in an

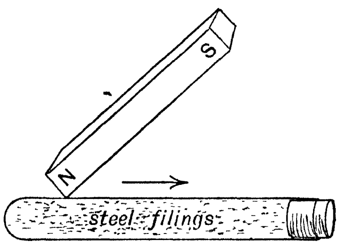


FIG. 236.
AN EXPERIMENT TO MAGNETISE STEEL FILINGS IN A GLASS TUBE.

orderly and linear arrangement. Each filing becomes a little magnet, and arranges itself in proper linear position relative to the other filings. So long as this linear arrangement of the filings is retained the contents of the tube behave as a bar magnet, capable of attracting iron filings, tacks, etc., but if the arrangement is shaken and the filings thrown into a disorderly mass, the magnetism ceases to exist as a force capable of influencing external objects.

This is true of magnets in general. The stroking process arranges the molecules or tiny particles of a steel bar so that they arrange themselves in a manner similar to that of the filings in a glass tube. Any process which disturbs the orderly arrangement of particles, such as banging the magnet on the floor, or heating it strongly, destroys the magnetism. This explains why magnets lose their magnetism if they are not handled carefully.

What happens if iron filings are placed in the tube instead of steel? It will be found that the *iron is magnetic only so long as it is under the influence of a magnet*, whereas steel once magnetised retains its magnetism, whether another magnet be present or not, provided that it is treated properly. This difference in the magnetic behaviour of iron and steel has proved extremely valuable, since the working of many electrical machines depends upon this property. If iron, once magnetised, retained its magnetism, electric appliances, such as bells, motors, and dynamos, would not work properly. On the other hand, magnetos employed on motor cars, and the indispensable mariner's compass used for steering ships, are examples of appliances which depend upon the fact that steel retains its magnetism.

Another difference must be noted. Iron, provided it is adequately excited by suitable magnetic means, is capable of exerting a much greater magnetic force than steel can in similar circumstances, and this is again fortunate since iron *must* be used in electric motors, dynamos, and many other machines.

Since steel retains its magnetism, a single bar magnet can be used to magnetise any number of steel objects, but it must not be concluded from this that we obtain something for nothing. Several magnets may be made, each capable of lifting nails or doing

other work, because of the mechanical work done in stroking the various pieces of steel. Energy has been expended in the process of magnetisation and in virtue of that energy we may obtain magnetism capable of doing work.

We have seen that magnetism is in some way connected with an orderly arrangement of the ultimate particles composing a substance, and a particularly important result of such linear arrangement is the property known as **polarity.** Any properly magnetised bar has two poles of equal magnetic strength, but these poles differ in their behaviour towards other magnetic bodies, because the inherent magnetic properties of one pole are not the same as those of the other. When a bar magnet is either suspended by a fine thread or floated upon a piece of wood in water, it swings round until it comes to rest with one end pointing to a position near the geographical north, the other end pointing roughly towards the geographical south. The end which points northwards will continue to point northwards every time the experiment is tried, unless the magnetism is destroyed or reversed. For this reason the pole near that end is popularly called a north pole, though the term *north-seeking* pole is more accurate. Similarly, the pole near the other end is called a south or *south-seeking* pole.

A bar magnet properly mounted so that it is quite free to move in a horizontal plane is called a **compass needle,** since the magnet is very much longer than it is wide. One clearly marked end or north pole of such a compass always points towards the north, hence the great value of such an instrument in navigation, exploration, and surveying. Of course, any compass indicates direction correctly only provided that it is not improperly influenced by any lumps of steel or iron placed near it, hence a ship's compass must be suitably screened from iron and steel parts of the ship. The binnacle which contains a ship's compass also contains *corrector* magnets to counterbalance undesirable magnetic influences.

The **mariner's compass** consists of a magnetised bar with a card bearing the various directions—north, south, etc.—correctly mounted above and firmly attached to it, so that as the magnet moves in relation to the ship's course, the card moves with it.

The box containing the compass is mounted by means of gymbals, so that whichever way the ship may roll the compass remains in a horizontal position. In a surveyor's compass the magnet is above the card, which is stationary; the needle alone moves according to direction.

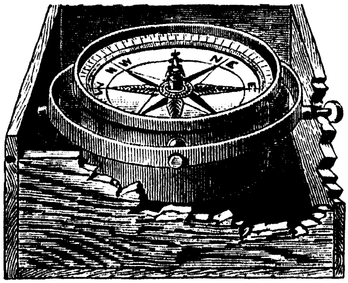


FIG. 237.—A MARINER'S COMPASS.

In order to understand why a magnet arranges itself roughly in a north and south line, we must consider polarity again. If the south pole of any bar magnet is brought near the north pole of a compass needle, the latter is attracted to it, but if the magnet's north pole is brought near the north pole of the compass, the latter is repelled or pushed away. All properly magnetised magnets and compass needles will give similar results, hence we have a most important law concerning magnetism—*there is mutual attraction between unlike poles, but mutual repulsion between like poles.* Now the earth behaves as if it contained a huge magnet extending through it, with its north magnetic pole somewhere near the geographical north pole, and the south magnetic pole near the geographical south pole. The earth's magnetic pole situated in the north possesses that kind of magnetism which attracts the so-called north pole of a compass while the magnetic pole in the south of the earth has magnetism of the opposite kind and attracts the so-called south pole of the compass. Hence it is more correct to speak of the north-seeking pole of a magnet.

Though the magnetic and geographical poles have sometimes coincided in past times, they do not do so at present, the magnetic north being now a few degrees west of geographical north. It follows from this, that there is at any place a geographical north and south line or meridian, which may or may not coincide with the magnetic meridian. These two lines intersect, forming an angle which is called the **magnetic declination** at the places, and in navigation allowance must be made for this in order that a

course set out on a map may be followed. Maps or charts showing the magnetic declination at different parts of the world are prepared for this purpose.

THE MAGNETIC FIELD

Around any magnet, whether it be that of the earth or a small compass, there is a region in which the influence of the magnet can be experienced by other magnetic bodies, pieces of iron or steel. This region of influence is called the **magnetic field.** In the case of the earth, the field exerts its influence all over the earth's surface, so that a compass anywhere sets itself according to magnetic north and south. It should also be noted that the earth's influence is *directive* only ; the compass is not pulled towards one part of the earth, since both ends of a small magnet are practically at the same distance from the earth's magnetic poles. In the case of an ordinary bar magnet, the extent of the field or region of influence depends upon the strength of the magnet and upon the nature of the substances or media surrounding the magnet. The stronger the magnet the more extensive the field, and substances like sheet iron which absorb magnetic influence produce non-magnetic gaps or **neutral spaces** in the region around a magnet.

The effect produced when a piece of iron is brought within the magnetic field is of the greatest importance in connection with the working of modern electro-magnetic machinery. A lump of iron (or steel) placed near a magnet arranges its molecules in orderly fashion and acts as a magnet itself, even though it is not touching the influencing magnet. The iron is then said to be magnetised by **induction** or influence, and the magnetism will last only so long as the iron is within the field of the inducing magnet. Should the inducing magnetism be cut off suddenly, the induced magnetism in the lump of iron instantly disappears, and this is exactly what happens in certain electrical machines we shall consider presently.

ELECTRO-MAGNETIC APPLIANCES

A wire along which an electric current is flowing has a magnetic field and acts as a magnet. For the present we cannot

discuss the nature of electricity itself, but must accept the fact that electricity is something obtained from a battery or other source and that it can be conducted along copper or other metallic wires. In any battery, such as those used in flash lamps or in wireless sets, there are two terminals, one marked with a + and called positive, the other marked − and called negative. Now if these two terminals are connected by a wire, a current of electricity flows along the wire from the positive to the negative terminal.

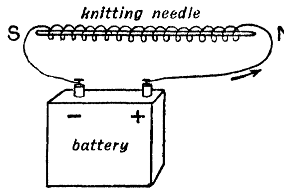


FIG. 238.
HOW A PIECE OF STEEL MAY BE MAGNETISED BY AN ELECTRIC CURRENT

When a wire carrying an electric current is held near a compass needle the compass is deflected to one side each time the current is started, and which way the compass needle moves depends upon the direction of the current along the wire. Thus this wire, although composed of copper, has a magnetic field around it so long as the current flows; directly the current stops, the magnetic field disappears. The ordinary electric telegraph is a magnetic needle influenced by the starting and stopping of a current. The rule formulated by both Ampère and Oersted, states that, *if you imagine yourself flowing with the current and facing the compass needle, its north pole will be deflected to the left.*

The magnetic field of a current can be used for other purposes. If a yard of wire covered with cotton or other material used to prevent the wire in the coils from touching one another is wound round a steel knitting needle as shown in the illustration (Fig. 238), and then the ends of the wire connected to the terminals of a battery, so that a current flows along the coil of wire, the needle will be magnetised and the polarity will be according to Ampère's rule. In this case the needle is magnetised by induction, but the inducing magnetism is due to electricity and not to an ordinary steel magnet. The needle, being steel, will retain its magnetism; and this method provides us with an easy way of making magnets. If a bar of soft iron is used in place of the knitting needle, it will remain a magnet only so long as the current flows.

Thus, a coil of covered wire wound around an iron bar makes an arrangement in which we can develop or destroy magnetism at will, merely by starting and stopping a current flowing along the wire. Such arrangements, known as **electro-magnets,** are of the greatest use in daily life, one of the simplest and most widely used appliance having an electro-magnet being the ordinary **electric bell** (Fig. 239). In this the electro-magnet is of the 'horseshoe' pattern and consists of two pieces of iron connected by a cross-bar. The covered wire is wound first around one of these pieces of iron and then without being broken it is wound in the opposite direction around the other piece. This reversal of the wiring ensures that the outer end of one piece is a north pole and that of the other piece is a south pole, an arrangement similar in this respect to the ordinary steel horseshoe magnets sold in toy shops.

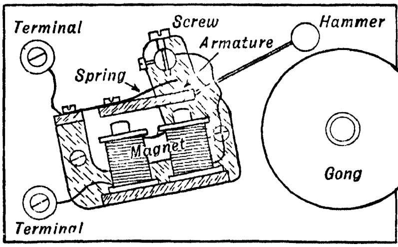


FIG. 239.—AN ELECTRIC BELL.

The polarity of the ends of an electro-magnet depends upon the direction of the winding and upon the direction of the current flowing along the wire. In the working of an electric bell, and in that of many other appliances, it does not matter which pole is north or south, and this means that it is immaterial which way the current flows. Facing the poles of the electro-magnet is a flat piece of iron connected to a rod and hammer which strikes the gong when the iron piece is pulled over towards the magnet directly the current commences to flow. But if the current continues to flow the iron piece is held there, and the gong is hit only once.

An arrangement for starting and stopping the current in rapid succession is necessary if the bell is to continue ringing. Such an arrangement is termed a *make and break*, since it repeatedly makes and breaks the pathway traversed by the current, and a current will flow only as long as the pathway or **circuit** is unbroken. The moving iron piece, technically known as an

armature, is also connected to a horizontal spring against which the point of a screw presses when the bell is not in use. This screw and spring form part of the circuit for the current.

A person operating the bell ' push ' bridges another gap in the distant part of the circuit, so that electricity flows along the wires and reaches the bell ; the magnet then pulls over the armature

FIG. 240.—WITTON-KRAMER CIRCULAR LIFTING MAGNET ON OVERHEAD TRAVELLING CRANE, HANDLING PIG-IRON.
(By courtesy of Witton-Kramer Works.)

and in doing so causes a gap between the screw and spring. The circuit being thus broken the current stops, the magnetism of the electro-magnet disappears, and the armature actuated by the spring moves quickly back to its first position, whereupon the screw again touches the spring, the current flows once more, and the whole process is repeated.

Electro-magnets of large size and power are used for picking

up and transporting iron and scrap-iron in engineering and other works (Fig. 240), while others of special construction are employed in surgery for the removal of iron and steel objects embedded in the body.

THE PRINCIPLE OF THE DYNAMO

Magnetism can be produced by means of current electricity, and the converse is equally true and important: electric currents can be produced by the influence of magnetism. These electro-magnetic machines which supply current for our domestic use,

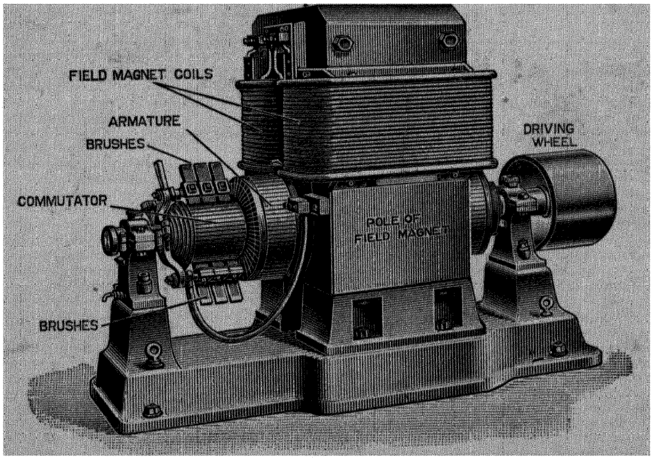


FIG. 241.—A DYNAMO.

public traction, etc., are the result of the work of one of the great outstanding scientific figures of the nineteenth century. **Michael Faraday,** the son of a London blacksmith, started life as an errand boy and carried out many experiments on magnetism at the Royal Institution, of which he eventually became director.

The electric currents obtained from batteries are feeble compared with those obtained from **dynamos** or machines in which electricity is generated by the influence of magnetic fields (Fig. 241). The principle of the dynamo can be stated very simply. If a complete loop of wire is placed near, that is, within the field

of, a magnet, no electric current is produced so long as both the loop and the magnet remain at rest. But should either of them move relative to the other, the magnetic influence exerted upon the loop of wire varies, and this *variation in intensity* of a magnetic field produces electric currents in the loop of wire. As the wire moves nearer to or farther from the magnetic pole, the magnetic field influencing it increases or decreases, and the quicker the rate at which this variation can be produced the greater is the electrical effect within the wire.

A very simple kind of dynamo called a **magneto** consists of a steel horseshoe type of magnet with a rotating coil of covered

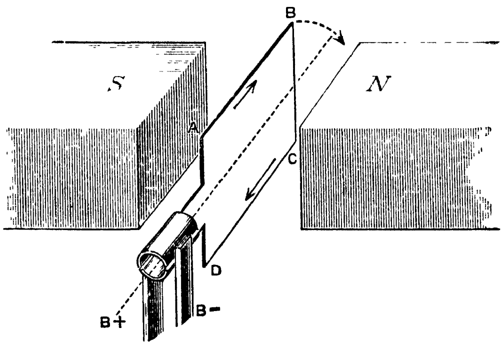


FIG. 242.—DIAGRAM ILLUSTRATING THE PRINCIPLE OF A DIRECT CURRENT DYNAMO.
THE ARMATURE IS REPRESENTED BY A SINGLE LOOP.

wire placed between the two poles of the magnet. Magnetos are used chiefly on motor cars for the production of electricity necessary for firing the gases in the engine. The motor engine, of course, supplies the power for making the coil of wire rotate in the magnetic field, only a small fraction of the total engine power being required for this purpose. The movable coil of wire in a magneto or dynamo is called the **armature**, and we must consider the means by which currents developed in the armature can be taken by wires to other places and made to do useful work, such as house lighting, heating, the operation of trams, railways, etc.

The arrangement for taking off the current is placed on the

axle of the armature, and generally consists of metallic rings upon which pieces of metallic gauze called **brushes** press so that a good contact is produced (Fig. 243). Wires connected to these brushes conduct the current to the place or places where work is to be performed.

The armature of any dynamo contains many turns of wire, and the mode of wiring is usually complicated, but the function of an armature can be understood by the consideration of one turn of wire only (Fig. 242). As the loop makes one complete rotation it passes twice through the vertical position of maximum magnetic influence (as figured), and twice through the horizontal position of minimum influence, and further, the part of the loop that was uppermost (AB) during the first half of the rotation is underneath during the remainder of the rotation. During the first half rotation the upper part of the loop proceeds from a south magnetic pole towards a north pole, but in the other half rotation it proceeds from a north pole towards a south pole. Corresponding changes occur in the other half of the loop. The result of this is that during one complete rotation two distinct currents, first flowing one way in the loop, then in the other direction, are produced.

Such currents which rapidly change their direction are said to be **alternating**. What is true for a single loop is true for all the windings of an armature, the currents are always alternating.

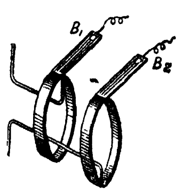


FIG. 243.—SLIP RINGS AND BRUSHES
FOR TAKING OFF THE CURRENTS FROM AN ALTERNATING TYPE OF DYNAMO.

If each end of the loop is taken to a separate metal ring on the axle, the electricity is taken off by the brushes as an **alternating current** and the machine is then known as an **alternator** (Fig. 243). At the present time much electricity of the alternating type is used for house lighting, domestic purposes, tramcars and railways, but in such cases the motors of trams, etc., must be wound in such a way as to function with alternating current.

For some purposes, the charging of accumulators for example, alternating current cannot be employed, hence the use of dynamos constructed to give a *direct* current, that is, a current which flows

always in the same direction. On the axle of a direct-current dynamo is an arrangement called a **split ring commutator** or current reverser. If the armature were a simple loop, this would consist of two almost semicircular pieces of metal separated by slight gaps and each connected to an end of the loop (Fig. 242). Each piece is positive during one half of a rotation and negative during the other half. It happens that when one piece is positive, or sending the current out to the external wires, it touches that brush which always remains positive, then during the other half of the rotation the other piece of metal becomes positive and comes in contact with the *same* brush. By this means the current which is alternating in the armature is passed to the external wires and machinery as a one-direction current. In a complicated modern dynamo the armature consists of many distinct loops and windings, each communicating with a metallic segment forming part of a much divided ring on the axle.

Can the electricity generated in a dynamo be used to strengthen the magnetism of the magnets? This is exactly what is done, of course iron being used for the field magnets instead of steel as in a magneto. Wires are taken from the armature and passed around the magnets, and dynamos differ in design according to whether all or part of the electricity available is to be passed around the field magnets. Dynamo design is beyond the scope of this book, but it may be said that most machines in common use are constructed so that part of the available electricity is used for exciting the magnets.

THE ELECTRIC MOTOR

Apart from slight modification, **electric motors** are very similar to dynamos; in fact, if a current be passed through the windings of a dynamo it will function as a motor. But in practice it is better to construct a machine for use either as a dynamo or as a motor. In a dynamo, power from some source, steam, gas, petrol, or water, causes an armature to rotate with the result that electricity is produced, but in a motor electricity is passed through the machine, with the result that the armature rotates and its motion may be used to operate other machinery. The armature

is caused to rotate by the strong forces of attraction and repulsion developed within the magnetic field. A motor, then, has precisely the same parts as a dynamo—field magnets, armature, split ring commutator and brushes. One very important fact concerning motors must not be overlooked. The armature is rotating in a magnetic field and there is a tendency for the machine to act as a dynamo setting up a current in opposition to

FIG. 244.—ELECTRIC CAR USED AT LARGE RAILWAY STATIONS.
(By courtesy of Electricars Ltd.)

that causing its rotation. This means that the current operating the machine as a motor must be considerably stronger than any opposing current the armature could generate.

The part played by electric motors in commercial and domestic life is enormous. Large motors are used for the propulsion of electric trains and trams and for the operation of machinery in factories, while small ones are used for fans, vacuum cleaners, sewing machines, etc. In a **vacuum cleaner** a fan worked by the

motor rotates in a nearly closed space, thus causing a current of air to pass through the machine into a bag. Dust and dirt are taken with the air into this bag, the material of which is porous, allowing the air to pass out, but not the dust, etc.

THE TELEPHONE

A most useful instrument making use of the interrelation of magnetic fields and electric currents is the **telephone.** We shall understand the working of this instrument if we consider the simple arrangement invented by **Bell** many years ago (Fig. 245).

One end of a steel magnet supplies a magnetic field which influences a coil of covered wire wound around it. The ends of this wire go to terminals connected to the line wires which similarly connect with a similar telephone at the other end of the line. A little in front of the magnetic pole is a flat thin

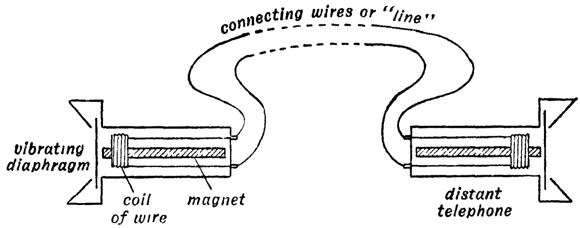


FIG. 245.—THE BELL TELEPHONE.

iron disc, which is made to vibrate by the sound waves produced by a person speaking into the mouthpiece. The vibration of this disc causes corresponding vibrations in the magnetic field influencing the coil of wire, with the result that fluctuating electric currents are set up in the wire and line. These currents produce similar variations in the magnetic field of the distant telephone, with the result that the disc there vibrates exactly as does the disc at the transmitting end, and the sounds of the voice are faithfully reproduced.

If the line is very long the electric currents are very much weakened, hence in modern telephony a current is supplied by a battery and the sounds are reproduced because the current is

modified in accordance with the variation in the magnetic field of the telephone ; in other words, variations are imposed upon the current from the battery. Loud speakers used for wireless reception are merely large telephones and work in a similar manner, the current delivered by the wireless set causing the disc or diaphragm of the speaker to reproduce certain sounds.

A telephone is operated by variations in the strength of an electric current, and these variations may be produced by other means. In the **carbon microphone,** a carbon-rod (or granules in some forms of telephone) makes loose contact with adjoining parts of the circuit, and under the influence of the voice or music the contact becomes better or worse as the case may be, and these variations in contact produce the required variations in the current operating the distant telephone.

Other instruments employing the influence of electric currents on magnets are certain kinds of meters for measuring electrical energy. These will be considered later.

CHAPTER XXVIII

OTHER KINDS OF WORK A CURRENT CAN DO

Electricity in flowing along metallic or other substances meets with a certain amount of opposition called **resistance.** Some substances offer much greater opposition than others ; those, such as metals and carbon, which make relatively slight resistance, being called conductors, while materials such as rubber, silk, glass, porcelain, and mica offer such a high resistance that practically no electricity passes at all, hence they are known as **non-conductors** or **insulators.** A silk or rubber covering on a wire insulates or shuts off the electricity in the wire from the surrounding objects. For the same reason protective rubber gloves are sometimes worn by electricians when repairing overhead tram-wires or other electric mains. When, however, they are working on a high wooden ladder or stand, the structure itself is often a sufficient insulator. Pieces of porcelain are used to insulate telephone wires, wireless aerials, etc., and mica is employed to separate certain parts of electrical machines. Since water conducts electricity *if the voltage is high*, these insulators function properly only when they are kept free from moisture. Soot, a form of carbon obtained from the smoke of chimneys, is also a conductor, so that the insulators of a wireless aerial should be cleaned periodically if best results are to be obtained.

HEATING AND LIGHTING

Even the better conductors, such as copper and mercury, offer some resistance, but certain other materials, while allowing a current to pass, offer sufficient resistance to cause a large amount of heat to be produced as the result of the conflict between the conducting substance and the electricity being forced along it.

Certain metals, usually alloys, such as platinoid and german silver, offer just the correct degree of resistance for wires composed of these materials to become red hot when electricity at the right pressure is being passed along them. Electric cooking stoves, flat irons (Fig. 246), and so-called 'electric fires' for heating rooms (Fig. 247), all use high resistance wires which become red hot when the electricity is switched on. These wires are of course insulated from the metal framework of the stove, iron, or heater as the case may be.

In some electric cookers the boiling plates used for kettles, saucepans, etc., consist of wires embedded in oxide of mag-

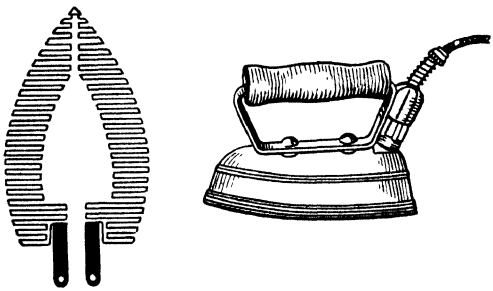


FIG. 246.—AN ELECTRIC IRON
AND ITS 'ELEMENT' OR WIRE WHICH BECOMES HEATED BY THE CURRENT.

nesium and completely covered by an outer casing so that water and grease cannot spoil the wires. This type of boiling plate retains its heat for a long time after the current has been switched off and is therefore economical. In electric fires of the 'bowl' type the resistance wire or *element* is placed in the position of the principal focus of a curved polished metallic reflector, so that the heat is projected better into the room.

Another practical application of the heating effect of an electric current is the use of thin fuse wires composed of pure tin which melts if the current is too strong, and thus breaking the circuit or pathway of the electricity, stops the current and prevents the overheating of conducting wires which might cause a fire. (Fig. 248.) The circuit of every house supplied with electricity contains a porcelain box fitted with several fuse wires each of

which controls the current in a certain part of the building, and one, the main fuse, controls the current entering the house from the external main wires.

Both electricity and heat can perform work, and there is a definite relation between them, or more correctly, there is a relation between all three, electricity, heat, and work. The connection of heat and work has been described in a previous chapter (XIX).

The amount of heat developed in a given resistance wire, for example that of a small bowl fire, depends upon three things:

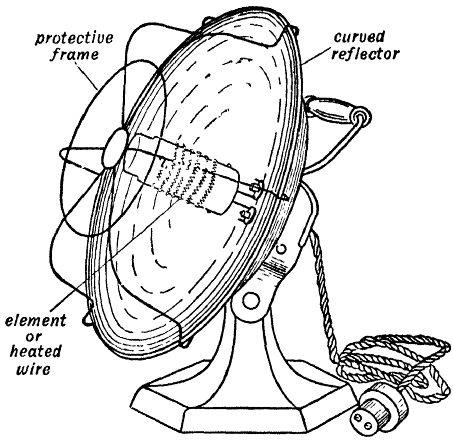


FIG. 247.—AN ELECTRIC BOWL FIRE.
THE HEATED WIRE IS SITUATED NEAR THE PRINCIPAL FOCUS OF A CURVED REFLECTOR.

(1) the resistance of the wire, (2) the time the current is allowed to flow, and (3) the square of the current strength. The first two factors are fairly obvious, but a word of explanation may be necessary concerning the third. If there are two different currents available, one just double the strength of the other, then this stronger current will develop not twice, but four times as much heat as the other in the same time and with the same resistance wire. These facts can be demonstrated experimentally by quite a simple apparatus. A definite volume of water at a certain initial temperature is placed in a glass vessel, which also

contains a covered wire having a definite resistance, and a thermometer. The rise in temperature of the water will be directly proportional to the amount of heat developed in the resistance wire. By using currents of different strengths and wires of different resistances, and by noting the time in seconds and the rise in temperature in each case, the facts stated above can be proved.

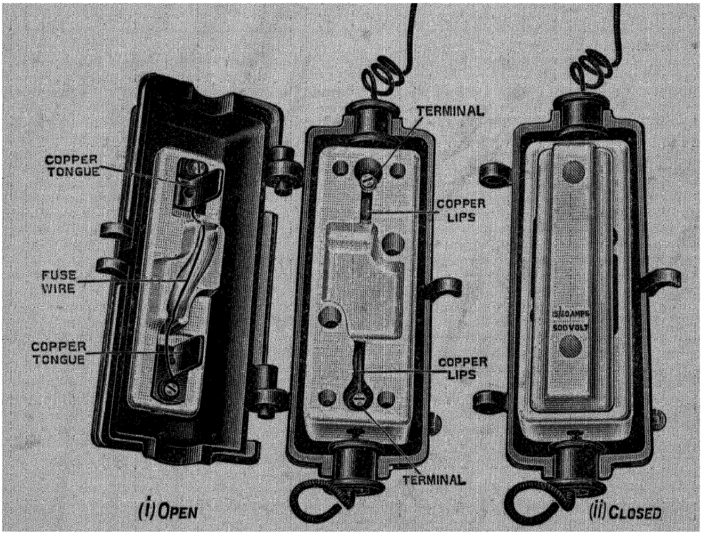


FIG. 248.—AN ELECTRIC FUSE WIRE AND ITS CONTAINING BOX.

If the heat developed is sufficient to render a wire white hot or incandescent, light as well as heat is emitted. This is the principle of the ordinary electric lamp in which a thin wire or filament is strongly heated by the passage of electricity. (Fig. 249.) The wire is thin, because such wires offer much greater resistance than thicker ones, and considerable resistance is necessary if the wire is to become luminous. The nature of the substance forming the filament also has some influence on the resistance, and in general the resistance increases as the temperature rises. The earliest electric lamp invented by **Edison**

many years ago employed a thin carbon filament, but now certain metals, particularly **tungsten,** obtained from a mineral called **wolfram,** and **tantalum,** obtained from **tantalite,** are in common use, though for some purposes carbon filaments are still employed.

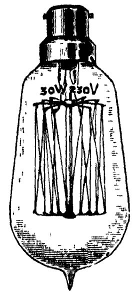


FIG. 249.—AN INCANDESCENT ELECTRIC LAMP HAVING A METALLIC FILAMENT.

In order that metallic filaments shall not oxidise or rust, oxygen must be removed by pumping out the air, or as is more often the case now, some inert gas such as nitrogen and other gases present in the atmosphere occupy the space instead of air. Such lamps are said to be *gas filled*. The amount of electrical energy consumed by lamps of various sizes is discussed in Chapter XXX. Though lamps of the incandescent filament type are now much more used for street lighting than formerly, a large and powerful street light known as an **arc lamp** makes use of an intensely luminous stream of heated carbon particles traversing a small gap between two rods of carbon. The stream of conducting particles extends in a curved line or arc from one carbon to the other, hence the name arc lamp. The carbons are slowly consumed, necessitating periodic renewal, and the lamp itself is obliged to contain some automatic electro-magnetic device for bringing the carbon rods nearer together again when the gap becomes too large and the light is extinguished. When alternating current is used the two rods are consumed at the same rate, but if direct or one-way current is employed, the positive rod wears away at a greater rate than the other, since the stream of incandescent particles is always in one direction from the positive to the negative rod.

FIG. 250.—AN ELECTRIC ARC LAMP USED FOR STREET LIGHTING, ETC.

The carbon arc lamp, on account of the **ultra-violet rays**

emitted by it, is of considerable importance in modern medical practice. These rays have a marked tonic effect in cases of nervous debility and yield beneficial results in a large number of other diseases and disorders. The patient sits or lies in the

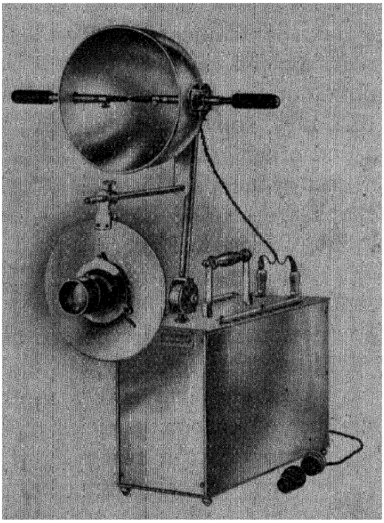


FIG. 251.—AN ARC LAMP USED FOR THE MEDICINAL APPLICATION OF ULTRA-VIOLET RAYS.
(By courtesy of Messrs. Ajax Ltd.)

glare from an arc lamp, placed at a definite distance, and the dose varies from one or two to several minutes. Since ultra-violet rays are injurious to the eyes, protective glasses must be worn.

ELECTROLYSIS AND ELECTRO-PLATING

An electric current can perform chemical work. If some crystals of copper sulphate, commonly called blue vitriol, are dissolved in water a blue solution is obtained from which the copper can be liberated by passing a current through it. The solution should be filtered and placed in a suitable vessel such

as a glass or earthenware pot. A piece of thin sheet copper is attached by a wire to the *positive* terminal of a battery or accumulator, while some object, say an old spoon, to be plated with copper, is similarly connected to the *negative* terminal of the battery. (Fig. 252.) The copper and the spoon are then placed in the solution near each other but not touching, and after a time a thin covering of copper appears on the spoon. The copper deposited comes from the solution and an exactly equivalent weight of metal from the sheet metal goes into the solution, which thus holds the same amount of copper sulphate as long as any of the sheet copper is left.

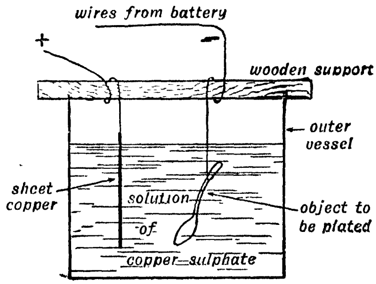


FIG. 252.—DIAGRAM REPRESENTING THE APPARATUS REQUIRED FOR COPPER PLATING AN OBJECT.

How is this transference of metal brought about? The electricity traverses the solution, but not in the same way as it passes along a piece of wire. Copper sulphate is composed of copper, sulphur, and oxygen combined together in the proportions represented by the chemical formula $CuSO_4$, where Cu stands for copper, S for sulphur, and O_4 for four atoms of oxygen. (Fig. 253.) The copper and sulphur are each present as one atom. Hence one extremely small particle, or molecule as it is termed, of copper sulphate contains an atom of copper, an atom of sulphur, and four atoms of oxygen.

The electric current is passed into the solution by the sheet copper and out of it by way of the spoon, and while this current is passing, the copper sulphate in solution may be regarded as consisting of two portions, or **ions**—copper, which is an **electro positive ion,** and the remaining sulphur and oxygen which together form an **electro negative ion.** Ions differ from ordinary atoms and molecules in that *they possess charges of electricity.* Thus an ion of copper is an atom of copper having a charge of positive electricity, and the remaining SO_4 group differs from a mere chemical combination of sulphur and oxygen in having a

charge of negative electricity. In a molecule of copper sulphate the two ions being together are properly balanced, the negative and positive mutually satisfying each other. But when the electricity is passed through the solution the sheet of copper attached to the positive plate of the battery attracts the negative SO_4 ions near it, and this sets free from the neighbouring molecules an equivalent number of positive copper ions which in their turn capture the negative ions of the other copper sulphate molecules near by, and so on through the solution. Finally, at the farther end some liberated copper ions yield up their electricity and as ordinary atoms of copper are then deposited on the spoon.

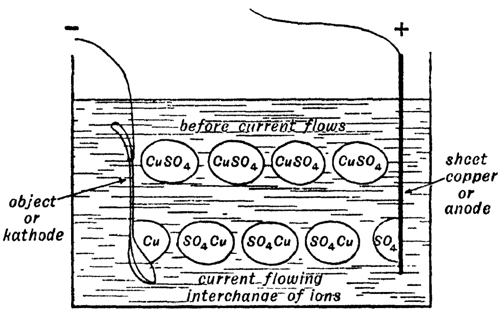


FIG. 253.—DIAGRAM REPRESENTING THE INTERCHANGE OF IONS WHEN AN ELECTRIC CURRENT PASSES THROUGH A SOLUTION OF COPPER SULPHATE.

This interchange of ions is illustrated diagrammatically in Fig. 253, but it must be realised that only a few of the vast number of ions can be represented. A solution which conducts electricity by this interchange of ions is called an **electrolyte,** and the process is known as **electrolysis.** The sheet of metal by which the current enters the electrolyte is called the **anode,** and that by which the current leaves the solution is termed the **cathode.** When objects are to be plated with a metal the anode must be a piece of the metal in question, the object to be plated forms the cathode, and the electrolyte must be a solution containing a soluble compound of the desired metal. Thus in silver plating, silver is the anode and a substance such as silver nitrate or cyanide is dissolved to

form the electrolyte In actual practice a fairly strong current is used, and all objects to be plated must be thoroughly cleaned of grease and dirt before they can be submitted to the process. Many large objects are **nickel-plated,** and smaller articles of jewellery are similarly covered with a thin layer of gold.

There is a definite relation between the strength of the electric current, the time it flows through the electrolyte, and the weight of metal deposited on the object being plated. This quantitative relation was first investigated by the famous Victorian physicist, **Faraday,** to whom we are also indebted for much of our knowledge concerning induced currents and the connection between magnetism and current electricity. **Faraday's laws of electrolysis** state (1) that the weight of any ion liberated, metal or otherwise, in a given time is directly proportional to the strength of the current, (2) with a current of given strength the weight of ion set free is directly proportional to the time the current flows, and (3) if the same current is passed through several different electrolytes the amount of chemical work done in one of them is equivalent to that done in any of the others. This last rule needs a little explanation. Chemically, 31·5 grammes of copper are equivalent to 108 grammes of silver, so that if the same current is passed through a solution of copper sulphate, and then through one containing silver nitrate, 31·5 gm. of copper are deposited in exactly the same time as 108 gm. of silver.

The relation between the current strength and the weight of metal deposited affords a very delicate and accurate mode of measuring the strength of a current, and a definition of the unit of current strength as found by this method is given in Chapter XXX.

Electro-plating is by no means the only practical application of electrolysis to metallurgical processes. Certain metals, particularly **potassium, sodium,** and **aluminium,** are obtained by passing powerful currents from a dynamo through suitable electrolytes. In these cases the electrolytes are not solutions in water, since water reacts violently with both potassium and sodium. The chief source of aluminium is a natural clay known as **bauxite.** Potassium and sodium are obtained by electrolysis of the fused hydroxide of each metal. A hydroxide

contains hydrogen and oxygen, besides the metal, and the ions liberated will be the metal and hydrogen at one end and the oxygen at the other. In another process fused salt or sodium chloride is electrolysed to obtain sodium, and in this case chlorine, a gas used in the preparation of bleaching powder and for other purposes, is also obtained.

In addition to the deposit or extraction of metals, electrolysis is very useful in many other ways. The hydroxides mentioned above are examples of *alkaline* substances, but some acids also form good electrolytes. If a little sulphuric acid is added to water, and a current passed through the solution, the ions liberated are hydrogen at the cathode and the SO_4 group at the anode, but the SO_4 cannot exist as a separate substance, so it reacts with the water taking hydrogen with which to form new molecules of sulphuric acid, and the oxygen of this water appears as a substance liberated at the anode. Thus, the substances which can be collected by the electrolysis of dilute sulphuric acid are hydrogen and oxygen, and the apparatus in which this is usually done is called a **voltameter** (Fig. 254). Since water consists of two volumes of hydrogen combined with one volume of oxygen, the volume of hydrogen collected in a given time will be twice that of the volume of oxygen. A very important practical application of this particular electrolysis is the **accumulator** or secondary cell described in the next chapter.

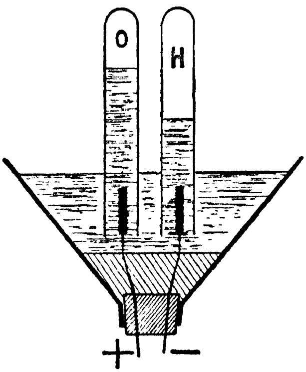


FIG. 254.—A VOLTAMETER.
ARRANGED FOR THE ELECTROLYSIS OF DILUTE SULPHURIC ACID.

If hydrochloric acid is electrolysed, the ions liberated in equal volumes are hydrogen and chlorine, and this affords a method of proving the composition of hydrochloric acid by volume. It must be noted *that hydrogen and metals always appear at the cathode*, and this fact affords a simple mode of testing the polarity of a battery or of a wire carrying a current. If such a wire is cut

and the two ends are kept a little apart and made to touch a piece of porous paper soaked with **potassium iodide** solution, a brown stain occurs on the paper near the positive wire where **iodine,** a non-metal, is being liberated by electrolysis.

In the treatment of some diseases, the application of iodine or some other ion is effected by an electrolytic process, the iodine being liberated and absorbed at the spot where the positive electrode is in contact with the patient.

CHAPTER XXIX

ACCUMULATORS AND VOLTAIC CELLS

As we have seen, an electric current can do very useful work of a chemical nature, and now we will consider the converse process, that of chemical work producing an electric current. A form of battery well known now on account of wireless apparatus is an **accumulator** which consists of several lead plates and dilute acid contained in a celluloid or glass case.

Though accumulators are not the simplest forms of apparatus for converting chemical energy into electricity, it is better to consider these first since their operation depends upon electrolysis, the kind of chemical change that was described in the previous chapter. Many years ago it was discovered by Grove that, if the terminals of a voltameter in which acidulated water had been electrolysed were joined by a wire, a feeble current passed along the wire. As the result of chemical work done in the voltameter by a current previously passed through it, a current in the reverse direction could afterwards be obtained from it. Thus, a *voltameter after electrolysis acts as a battery.* The separated ions, oxygen and hydrogen, tend to recombine and deliver up their electricity ; even when an electric current is being passed through the solution during electrolysis there is this tendency to recombine, a fact that explains why the current from only one ordinary cell is not sufficient to electrolyse acidulated water.

In **Grove's gas battery** several simple voltameters were joined together in series, that is, in such a way that the current passed through each voltameter in turn. This meant, of course, that the resulting current obtained from the arrangement after

electrolysis was much better than that from a single voltameter. This gas battery, the pioneer of the modern accumulator, apart from giving a feeble current, had numerous other disadvantages. For example, it was too large in proportion to results obtained, and it was not portable.

Planté's cell, invented in 1860, and having plates of ordinary metallic lead immersed in diluted sulphuric acid, represented a later stage in the evolution of the accumulator. The process of charging a Planté accumulator was tedious, the charging current having to be sent for some time in one direction, then for some time in the other direction. Planté cells resembled modern accumulators in having, when charged, *the negative plate in the state of metallic lead, the other or positive plate being covered with a dark brown substance known as lead peroxide.* In a present day accumulator, used for wireless and other purposes, there are several positive plates connected together but prevented from touching a similar set of connected negative plates (Fig. 255). All the plates are immersed in dilute sulphuric acid, the whole being contained in an outer case usually composed of celluloid, or of glass in the case of large accumulators used for country house lighting, etc. Vents or small openings in the case are supplied to permit the escape of gases formed as the result of the chemical changes taking place within.

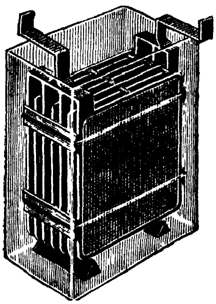


FIG. 255.
AN ACCUMULATOR.
USED FOR HOUSE LIGHTING, ETC.

As early as 1881 it was found that if the leaden plates were both coated with a layer of red powder known as **red lead** (another oxide of lead) they were more quickly brought, on charging, to the required condition. Other improvements have been introduced, so that modern plates are made in the shape of a grid having numerous square spaces which are filled with a paste of red lead (Fig. 256).

The first or initial charge given to an accumulator always takes some time and requires considerable care, hence the higher price

asked for this initial charge. The sulphuric acid employed must be of the right strength, and this is tested by determining its relative density or specific gravity by means of a hydrometer. The density alters as the accumulator is being used, so that after discharge it is about 1·18. A solution of the right strength is prepared by mixing acid with water, the mixture having a specific gravity of about 1·250

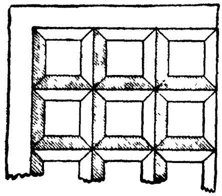


FIG. 256.—PART OF AN ACCUMULATOR PLATE SHOWING THE 'GRID' PATTERN.

It is not easy to describe in simple language the exact nature of the chemical changes which take place within an accumulator before and after discharge. While the charging current is being passed through the apparatus the ions liberated by the electrolysis are hydrogen and oxygen, the former appearing at the negative plates and reducing their surfaces to the state of soft spongy lead, while the oxygen appearing at the positive plates supplies additional oxygen required to convert the surfaces to peroxide of lead. After the accumulator has been used as a battery and has been discharged, both sets of plates are coated with a whitish substance called **lead sulphate,** and should the apparatus be allowed to stand in the discharged condition for a long time, this **sulphation** seriously damages the plates. Accumulators are kept in order by constant use and recharging.

The amount of electricity that an accumulator can yield after a single charge depends upon its capacity, and of course upon its being properly charged. The capacity depends upon the number and size of the plates, larger and more numerous plates naturally having greater capacity than smaller and fewer plates. The capacity is generally stated on the accumulator, and is expressed as so many **ampere hours.** An accumulator having a capacity of 40 ampere hours (continuous, not ignition), will yield a current of one ampere for 40 hours, or a current of ½ ampere for 80 hours, and so on. For the ignition of gases in a motor engine the time is twice that of continuous use, since the current is used only intermittently. A more detailed description of the unit called an ampere is given in Chapter XXX, where electrical

units are discussed, and where the voltage of accumulators and batteries is also explained.

It must be clearly understood that when an accumulator is 'charged,' electricity is passed through it and *not stored in it* in the form of electricity as water can be stored in a bottle. The chemical changes brought about by the passage of the charging current are such that when later the terminals of the accumulator are connected, other chemical changes then produce a current. Accumulators, since they produce electric currents as the result of these **secondary chemical changes** due to electrolysis, are known as secondary cells, in distinction from the primary cells or batteries which yield currents due to chemical actions without previous electrolysis. Though most accumulators in common use have leaden plates immersed in sulphuric acid, there are others of recent design containing nickel plates in an alkaline paste composed of a whitish substance known as caustic soda. The operation of these is also based upon electrolysis, and the advantage is in having no fluid electrolyte that can be spilt, but the initial cost is relatively high.

PRIMARY BATTERIES USED FOR ELECTRIC BELLS, FLASH LAMPS, WIRELESS HIGH TENSION, ETC.

Quite as well known as accumulators are the small dry cells used for lighting little pocket electric lamps, ringing bells, etc., and we must now consider the construction and mode of working of these voltaic batteries.

Towards the close of the eighteenth century two Italian scientists laid the foundation of our knowledge concerning current electricity. **Galvani,** a physician, experimented upon the nervous systems of dead frogs and found that two dissimilar metals touching at one end and in contact with the frog's nerves at the other ends caused muscular contraction. **Volta,** a professor of physics, discovered that two dissimilar metals, copper and zinc, when placed in dilute sulphuric acid generated a current of electricity if the outer ends of the metals were connected by a wire.

If we are to understand the working of modern voltaic cells,

we must first examine the operation of the simple cell invented by Volta. When a piece of zinc is placed in sulphuric acid, bubbles of hydrogen, turned out of the acid, collect near and upon the zinc, but when a piece of copper is placed in the solution no action takes place between it and the acid, and the hydrogen still escapes near the zinc (Fig. 257). But if a wire now connects the upper ends of the metals the bubbles of hydrogen appear at the copper instead of near the zinc. *There is an interchange or migration of hydrogen ions towards the copper plate, thus causing it to send a current around the circuit.* Note that the solution between the two metals forms part of the circuit or pathway for the current, and that the direction of the current in the liquid is from zinc to copper.

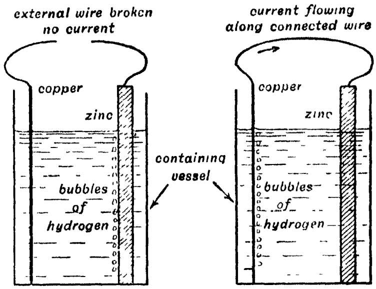


FIG. 257.—EXPLANATION OF VOLTA'S SIMPLE CELL.

The primary cause of the electrification is the chemical action between the zinc and the acid, and the electricity obtained must be regarded as equivalent to the chemical work done ; chemical energy is converted to that of electricity. The action being continuous, the cell is like a pump forcing electricity around the circuit, but the action will continue only as long as there is some undissolved zinc and as long as certain other conditions are fulfilled.

This simple electric cell has several disadvantages which make it of small practical value. It is not portable, and the current obtained is weak, but the chief trouble consists of the accumulation of hydrogen on the positive or copper plate. Once the hydrogen has given up its electricity it becomes a nuisance, forming a gaseous layer that slows the action down. This slowing down, due to the accumulation of hydrogen, is known as **polarisation,** and any cell to be of practical value must have some means of preventing such accumulation.

The process of doing away with the hydrogen after it has yielded its electricity is known as **anti-polarisation.** Some early

forms of cell attempted to get rid of the hydrogen by mechanical means, such as points on the positive plate, but this required periodic shaking. In modern cells the method of anti-polarisation is chemical, the hydrogen being supplied with oxygen from some substance rich in oxygen and ready to part with some. Such substances are known as **oxidising agents,** and they oxidise the hydrogen so that water is formed, and this prevents the formation of any gaseous film on the positive plate of a cell. Though nitric acid, and a yellow substance called potassium dichromate, are sometimes used in laboratory work, practically all primary cells employed commercially and in the home contain a black powder called **manganese dioxide** which performs the work of anti-polarisation.

Two kinds of cell more widely used than any others are that invented by **Leclanché,** and the **dry** cell. In the Leclanché (Fig. 258) a solution containing dissolved sal-ammoniac or ammonium chloride corresponds to the sulphuric acid in the simple cell of Volta. A cylindrical rod of zinc is placed in this solution which then reacts with it, so that hydrogen is given off. The positive plate of the Leclanché cell consists of a rod of carbon placed in an unglazed earthenware porous pot containing the black oxide of manganese and carbon grains. This porous pot and its contents are, with the zinc, placed in a square glass vessel containing the solution of sal-ammoniac. As stated above, the zinc liberates hydrogen ions from the solution, and these proceed through the porous pot to the carbon, where they deliver up their positive electricity, after which the hydrogen is oxidised by the manganese dioxide with the production of water, which slowly collects inside the porous pot, but can be drained away if the pot is occasionally removed and allowed to stand for a time. The carbon corresponds to the copper of the simple cell. The action between the zinc and sal-ammoniac is relatively quiet, and the

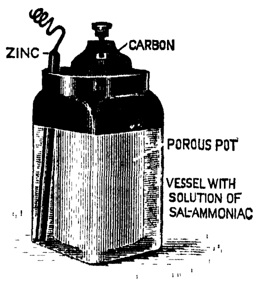


FIG. 258.—A LECLANCHÉ CELL.

metal may last a long time without being removed from the solution. This, of course, is a great advantage, and the length of life of the zinc may be increased by first cleaning it with dilute acid and then rubbing it with a little mercury.

This process is known as **amalgamation**, since a surface layer of zinc amalgam is formed. Amalgamation of zinc plates tends to prevent what is known as **local action**, or the generation of small unwanted currents in the zinc itself because of impurities in it. Antipolarisation in a Leclanché cell is fairly good, but the cell is most useful in connection with electric bells where an intermittent current only is required. An improved apparatus known as an **agglomerate Leclanché cell** dispenses with the porous pot, the manganese dioxide and powdered carbon being cemented to a

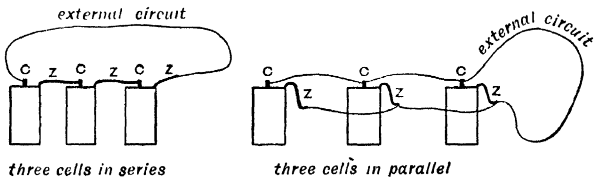


FIG. 259.—ELECTRIC CELLS ARRANGED IN SERIES AND IN PARALLEL.

C = CARBON. Z = ZINC.

compact mass placed outside of the carbon plate and kept in place by rubber bands. A better current is obtained, because the porous pot of the ordinary cell offers a resistance to the electric current.

Though a discussion of voltage is left for the next chapter, it may be as well to mention that the voltage of a single Leclanché cell is about 1·6 volts at first, but if the current is allowed to flow for some time, the voltage falls below this. If two cells, Leclanché or any other type, are connected together by joining the zinc of one to the carbon terminal of the next, the arrangement gives twice the voltage of one cell, and the cells are said to be joined in **series** (Fig. 259). If the two zincs are joined together, and the two carbons connected to each other, then the cells are joined in **parallel**, an arrangement in which the voltage is only the same as that of one cell, but the current is increased. Which

CHAPTER XXX

ELECTRICAL UNITS AND MEASUREMENTS

THE utility of current electricity depends chiefly upon the fact that it flows along metallic conductors or wires. What causes this flow of electricity? An answer to this question can be understood more easily if we consider the flow of water and the transference of heat, both of which are in many ways similar to the passage of electricity. Water flows from a higher to a lower level. If two tanks are connected by a pipe, water will flow from the tank where it is at the higher level into the other and will continue to flow until the water in both tanks is at the same level. Similarly if a cold object, such as a potato, is placed in a vessel containing hot water, heat will pass from the water into the potato and will continue to do so until both are at the same temperature. Temperature may be regarded as heat level. It must be clearly understood that quantity of water is not the same as water level, since a large volume of water may be at a low level, as in the case of a lake near sea-level, or a little water may be at a high level, as in a mountain stream. Water flows as the result of a *difference* in level quite apart from the quantity of water concerned. Similarly, temperature is not the same thing as quantity of heat.

THE RELATION BETWEEN VOLTAGE AND CURRENT

In electricity we have very similar characteristics. The correct name of the condition we may roughly describe as electric level is **potential**, and it is a difference of potential (P.D.) or **electromotive force** (E.M.F.) that causes a current to flow from one part of a circuit to another part. The height of a water column is measured in feet and this indicates the water pressure; similarly,

potential may be considered as electric pressure and is measured in units called **volts**. Just as water level indicates pressure and not quantity of water, so voltage indicates potential and not quantity of electricity. A small amount of electricity at a high voltage is analogous to a mountain stream, whereas a large quantity of electricity at a low voltage is similar to the water of a lowland lake.

The analogy between water and electricity can be carried a little farther. The water of a mountain stream falls until it reaches sea-level, that is, until its pressure becomes zero; similarly in any electric circuit the voltage falls to zero or no volts, and it follows from this that *the voltage is different at different parts of a circuit*. Consider the case of water of a mountain lake being conducted by pipes to a power-station lower in a valley. Of course the total pressure on the turbines in the power-house is equal to the complete head of water in the pipes, but the pressure at any point along the pipes is determined by the head of water above that point, hence the water pressure is different at different levels of the pipes. The amount of water passing through the turbines depends upon the size and number of the conducting pipes, the larger and more numerous the pipes the greater the quantity of water available in a given time. In electricity the strength of the current not only depends upon the pressure or voltage but also upon the size and kind of metallic or other conductors forming the circuit. Generally the thicker and shorter the wires the stronger the current.

The strength of an electric current is measured in units called **amperes**, and the *Board of Trade ampere is defined as being that current which will deposit* 0·001118 *gm. of silver from a solution of silver nitrate in one second by the process of electrolysis* described in Chapter XXVIII.

Wires and other conductors forming a circuit offer an opposition to the passage of electricity, and as we have seen in the previous chapter, this opposition is known as resistance. Just as narrow pipes prevent a good flow of water, so thin wires offer considerable resistance and weaken a current of electricity. The resistance also depends upon the kind of metal used, silver having less resistance than others, but copper or copper covered wires are used generally

as they are cheaper and nearly as good as silver. Other good conductors of electricity are brass, mercury, and carbon. Insulators such as rubber, porcelain, silk, glass, and mica, offer such high resistance that no current passes at all. In making comparisons of specific resistances, wires of equal length and thickness must be used. With any given metal, the resistance increases with length but decreases with thickness, and in the case of a wire of uniform thickness we have R varies as l/a, a formula in which R represents resistance, l means the length, and a is the area of cross-section.

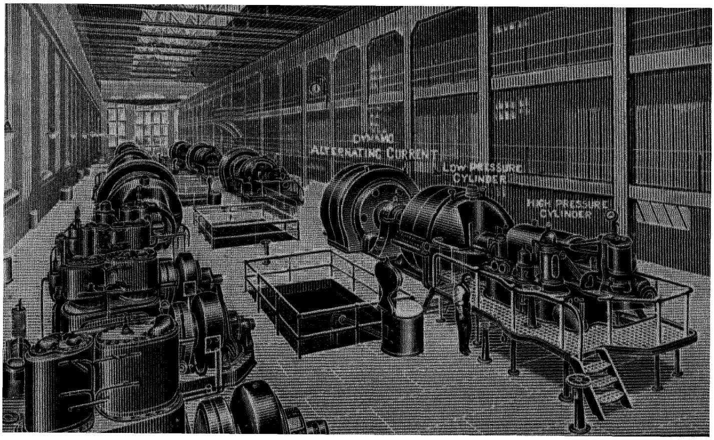


FIG. 262.—THE LOTS ROAD POWER STATION, CHELSEA, LONDON, SHOWING TURBINES COUPLED DIRECTLY TO ALTERNATORS.
(By courtesy of Messrs. C. A. Parsons Ltd., Newcastle.)

Of course carbon plates and solutions of electrolytes as used in accumulators and batteries also offer resistance, so that in any electrical circuit there is the resistance of the *external* wires and machinery denoted by the symbol R, and the *internal resistance* within the battery and represented by the symbol r. The total resistance of the complete circuit is therefore represented by $R+r$.

Calculations concerning voltage, current strength, and resistance are of great importance in electrical work of all kinds, and it is necessary to employ some unit of resistance. This unit is called an **ohm**, the name, as volt and ampere, being derived

from a pioneer of current electricity. One ohm is roughly the resistance of a piece of copper wire ten feet in length and about $\frac{1}{100}$ inch in diameter.

The relation between voltage or electromotive force (E), the resistance (R), and the resulting current strength (I) is expressed by **Ohm's Law,** which states that *the current obtained varies directly as the electromotive force and inversely as the resistance.* This expressed as a formula is $I = E/R$. Divide the E.M.F. in volts by the resistance in ohms and we obtain the current in amperes. From this it follows that one volt is that electromotive force which urges a current of one ampere along a circuit which has a resistance of one ohm. Also, it is obvious that from the equation $I = E/R$, any one of the three quantities can be calculated provided the other two are known.

Find the strength of the current when a 2 volt accumulator is used with a circuit having a resistance of 8 ohms. Here $I = \frac{2}{8} = 0{\cdot}25$ ampere. More accurately, we should include the internal resistance of the accumulator itself, and if this is 0·2 ohm, the formula is $I = \frac{E}{R + r}$, hence in this case $I = \frac{2}{8 + 0{\cdot}2} = 0{\cdot}244$ ampere, very nearly the same current, since the internal resistance of an accumulator is small. If several accumulators or cells are employed, the current obtained depends upon the way in which the cells are connected together. When the positive of one cell is connected to the negative of the next, and so on, the cells are arranged in *series* (Fig. 259), and the E.M.F. is that of the individual cells added together. But in this case the internal resistances must also be added, so that the series mode of connecting cells is suitable when the internal resistances are small compared with that of the external circuit. An example will make this clear.

Suppose that 4 cells are connected in series, each cell having a potential (E) of 2 volts and an internal resistance (r) of 0·2 ohm, the external circuit having a resistance (R) of 10 ohms. The current obtained will be according to the formula :

$$I = \frac{E_1 + E_2 + E_3 + E_4}{R + 4r} = \frac{8}{10 + 0{\cdot}8} = \frac{8}{10{\cdot}8}$$

$$= 0{\cdot}74 \text{ of an ampere, approx.}$$

But if the same cells are joined in *parallel* by connecting all the positive plates together and all the negative plates together, the voltage is only the same as that of one cell, but the total internal resistance is only $\frac{1}{4}$ that of one cell. It is the same as if we had one large cell with plates 4 times the size of those in one of the small cells. Hence in this case the formula is:

$$I = \frac{E}{R + \frac{r}{4}} = \frac{2}{10 + \frac{0{\cdot}2}{4}} = \frac{2}{10{\cdot}05} = 0{\cdot}2 \text{ of an ampere approx.}$$

The parallel method of connecting cells is better when the external resistance is small. Thus, with the cells as above, but the resistance of the external only 0·5 ohm, we have:

$$I = \frac{2}{0{\cdot}5 + 0{\cdot}05} = 3{\cdot}7 \text{ amperes.}$$

In most practical applications—bell and telephone circuits, the lighting of small lamps, electrolysis, etc.—it is usual to connect cells in series, since considerable lengths of wire, very thin filaments of lamps, and electrolytes all offer considerable resistance. A four volt accumulator really consists of two separate 2 volt cells connected in series.

We must now consider the results obtained when wires forming the external circuit are arranged in different ways, since different arrangements of the same wires alter the resistance R. Take first the simple case of a single 2 volt cell sending a current along a single copper wire of uniform thickness. Certain fundamental facts should be remembered—(1) the resistance is the same at all parts of the external circuit, and from this it follows that (2) the voltage falls uniformly along the circuit, and (3) the current strength is the same at all parts of an unbranched circuit.

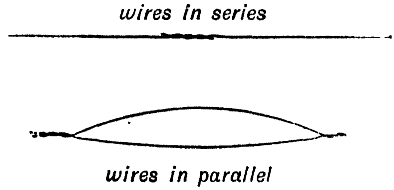


FIG. 263.—CONDUCTORS ARRANGED IN SERIES AND IN PARALLEL.

But if we have two wires, each having a resistance of say 5

ohms, we can arrange them in two distinct ways: in series, that is one after the other, forming an unbranched circuit, or in parallel forming a branched circuit as shown in the diagram. (Fig. 263).

When these conductors are joined in series the resistances must be added, but when they are in parallel, there is a better pathway for the current and the resistance of the two wires taken together is only half that of one of them. In the series arrangement R = 10 ohms, but with the wires in parallel R = 2·5 ohms, hence if the internal resistance of the cell is ignored, the parallel arrangement gives in this case four times as much current as the series arrangement. Here is a practical example. Compare the currents obtained when two electric lamps, each having a resistance of 400 ohms, are connected in series and in parallel, the E.M.F. of the mains being 200 volts. According to Ohm's Law, either lamp used by itself passes 0·5 ampere.

With the lamps in series we have:

$$I = \frac{200}{400 + 400} = \frac{200}{800} = 0{\cdot}25 \text{ ampere.}$$

The total current is only half that passed by either lamp used singly.

When they are in parallel:

$$I = \frac{200}{\frac{400}{2}} = \frac{200}{200} = 1 \text{ ampere.}$$

In this case each part of the branched circuit has the same resistance and each takes 0·5 ampere, but when the resistances are unequal, the portion of the total current taken by each branch depends upon its relative resistance, that wire having the higher resistance taking a smaller portion of the current than the other. Thus, supposing a wire having a resistance of 3 ohms is joined in parallel with one of 1 ohm, then, whatever the total current may be, the 3 ohm wire takes only $\frac{1}{4}$ of it, while the 1 ohm wire takes the other $\frac{3}{4}$. The same rule applies to any number of branches in a complex circuit, the pathway having least resistance carries more current than any one of the others.

It follows from the relation between resistance and current that wires of high resistance can be employed to cut down the current when desired, as in the control of tramcars and electric railways. The driver of a tramcar or train regulates the speed by switching in or out various resistances so that the current working the motors

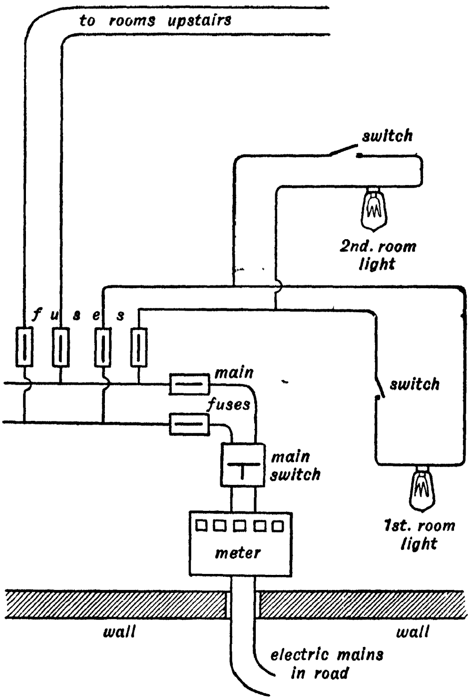


FIG. 264.—GENERAL PLAN OF WIRING OF A HOUSE FOR ELECTRIC LIGHT.

NOTE THAT CONNECTIONS ARE ALL IN PARALLEL, OTHERWISE SWITCHING OFF ONE LAMP WOULD SWITCH OFF THE WHOLE.

is correspondingly varied. These resistances are composed of metal (nickel-chrome) having a relatively high resistance and coiled so that a considerable length can be placed in a small space. Valves for wireless reception and many other forms of electrical apparatus are also controlled by adjustable resistances.

POWER CONSUMPTION AND ELECTRIC METERS

In the examples given above it is shown that the current obtained is greater when two lamps in parallel are used instead of one, and of course the consumer has to pay for the extra current used. If the lamps were joined in series the current would be reduced and the necessary degree of illumination would not be obtained. The electrical energy consumed in lighting, heating, or in any other form, depends upon both the voltage and the current used. Electrical power is measured in units called **watts,** and the number of watts is found by multiplying the volts by the amperes. Thus, if 200 volts are urging a current of 5 amperes along a circuit, the number of watts is 1000, or one **kilowatt.** If this current continues at the same voltage for one hour the energy consumed is a **kilowatt-hour,** or one **Board of Trade unit of power** This is the unit employed in the measurement of domestic and commercial electrical consumption, but various prices are charged by different local power companies. Both industry and domestic work will benefit considerably when the supply of electricity becomes more centralised and produced at a cheap uniform rate. As a rule a higher rate is charged for lighting than for heating, cooking, and other forms of power consumption, and two separate meters are used.

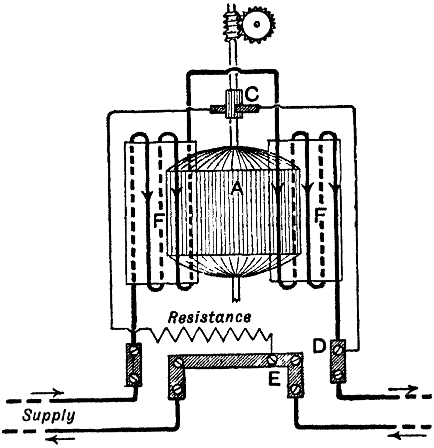


FIG. 265.—A METER FOR MEASURING ELECTRIC POWER.

UNDER THE INFULENCE OF THE CURRENT IN THE COILS *FF*, THE ARMATURE *A* ROTATES, AND ITS RATE OF ROTATION DEPENDS UPON BOTH THE CURRENT AND THE VOLTAGE, HENCE THE WATTAGE IS INDICATED.

One or two examples will illustrate the usual consumption in lighting, cooking, etc. An electric lamp commonly used in

sitting rooms of average size is marked 200 V., 100 W., and this means that this lamp consumes exactly 100 watts in an hour when the mains are at a pressure of 200 volts. If the unit of supply is rated at 6d. for lighting, such a lamp can be used continuously ten hours for 6d. Another lamp used in smaller rooms is marked 200 V., 40 W., and this consumes only 40 watts per hour, and can be used continuously 25 hours for 6d. A so-called half-watt lamp consumes half a watt for each candle power obtained. Of course, lamps and other appliances should always be used in connection with the voltage indicated on them. An electric oven of average size consumes 3000 watts per hour, and if the rate for power consumption is 2d. the cost of this is 6d. per hour. Similarly, a small bowl electric fire consuming one unit will cost 2d. per hour.

Instruments used for measuring domestic and other consumption of electricity are known as **wattmeters** (Fig. 265), and these measure the product of volts multiplied by amperes, but many separate instruments—**voltmeters** (Fig. 266) for measuring electro-motive-force and **ammeters** for amperes—are commonly used in laboratories, engineering works, and for testing batteries used in connection with bell circuits, telephones, wireless sets, etc. There are many types of these instruments, some much more complicated than others, and we can consider here only those of more simple construction, such as the small pocket voltmeter one uses to test an accumulator or high tension wireless battery. Those most commonly employed are electromagnetic in their mode of operation. The magnetic field of a wire carrying an electric current causes a movement or deflection of a small magnetised needle placed near the wire, or in many cases the coil itself is caused to move, and the extent of

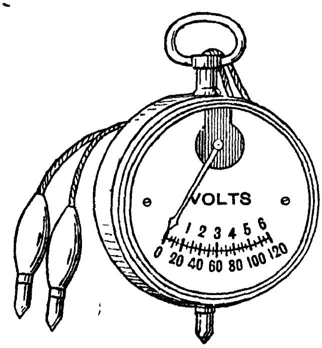


FIG. 266.—A POCKET VOLTMETER.

ONE OF THE TERMINALS ON THE LEFT IS USED FOR LOW VOLTAGES AND THE OTHER FOR HIGH VOLTAGES SUCH AS THAT OF A HIGH TENSION BATTERY USED WITH WIRELESS RECEIVERS.

this movement is related to the amount of current flowing along the wire.

If a wire is coiled around an ordinary compass needle the magnetic field of the current passed along it is balanced against the earth's magnetic field, which endeavours to keep the needle pointing magnetic north and south. Such an instrument, called a **tangent galvanometer,** works correctly only when it is previously placed in the right position with both the needle and the coil of wire in the magnetic meridian. Then the current strength has to be found by a calculation, and it is not read directly, so that it is better to use a different type of instrument in which the magnetic field of the current is not balanced against that of the earth.

Two magnetised needles of equal strength can be mounted together in such a way that the earth's field has no action upon the arrangement. The north pole of one needle is placed above the south pole of the other, and the two are firmly fixed together by a vertical bar. It is obvious that the action of the earth on one needle is counterbalanced by the action on the other, and such an arrangement is called an **astatic pair** (*i.e.* not standing), since it does not set itself pointing north and south as an ordinary compass does (Fig 267). If a coil of covered wire is placed around one of these needles, the magnetic field of a current passed along it can be balanced against a coiled spring or other device. Such a galvanometer can be placed in any position, and once it has been calibrated, or a scale of correct readings has been made, the current strength or voltage, as the case may be, can be read directly from a pointer which moves over the scale.

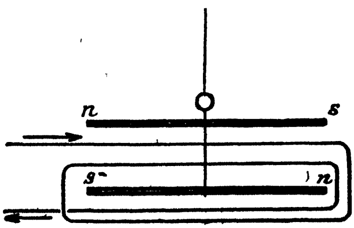


FIG. 267.—AN ASTATIC PAIR.

In an instrument designed for use as a voltmeter the coil consists of many turns of thin wire having a very high resistance, many hundreds of ohms, which is so arranged that it is always in parallel with the circuit being tested. In an ammeter designed

for measuring the amperes the instrument must not add any additional resistance, hence the coil consists of one turn of wide metallic strip and the full current of the circuit to be tested is indicated.

In some modern applications, such as X-ray work and wireless circuits, the currents are very small, a few milliamperes or thousandths of an ampere, and for measuring such currents a delicate and specially constructed instrument must be employed.

Wattmeters may be regarded as combined voltmeters and ammeters—in fact the wattage could be measured by means of a separate voltmeter and ammeter placed in the same circuit. The wattmeters used for measuring domestic and other consumption are self-recording, the total consumption being shown by figures representing units and tens, hundreds and thousands of units.

The insulation of electric lighting mains, and that of cookers and other apparatus, is tested by means of an **ohmmeter**, often termed a 'mega,' since it is capable of measuring resistances up to millions of ohms or **megohms**. In this instrument the current from a small hand-operated dynamo is passed along circuits arranged in such a way that any leakage in the mains or apparatus undergoing a test is indicated by a pointer and scale.

ELECTROMOTIVE FORCE THE RESULT OF WORK DONE

Mere quantity of electricity without pressure or voltage is of no use in practical life. In order to produce electricity at a potential high enough to do work, some sort of work must first be done. The potential of a voltaic cell is the result of chemical work done by the attraction of the zinc for part of the acid or other solution employed for that purpose. The more thorough this chemical work, the greater the resulting voltage, as shown by the better results obtained by cells having good means of anti-polarisation. In a dynamo the voltage depends upon the rate at which the magnetic field varies, and this of course depends upon the speed of the armature: more mechanical work must be done to rotate the armature quickly than is necessary for slower motion.

The power may be supplied by steam, petrol, coal gas, or falling water, but in all cases there is a definite relation between the amount of mechanical work done and electrical energy produced. A force that can lift 33,000 lb. weight through a distance of one foot in one minute is called one **horse power,** and this is equivalent to 746 watts, or 0·746 of the practical unit of electrical supply. As machines do not yield 100 per cent. of the energy employed to operate them, there is always some loss in changing mechanical force into electric power, also a certain amount of energy must be expended in overcoming the low resistance of the mains or conducting wires; consequently more than one horse power must be used at the power station to supply 746 watts for lighting or other purposes.

In connection with loss of energy and efficiency, it is better to use a high voltage and small current than a lower voltage and bigger current when transmitting electrical energy from a power station to some distant place. Two thousand watts could be transmitted as a current of 10 amperes at 200 volts, but it is better to transmit it as a current of say one ampere at 2000 volts. At the farther end where the electricity is to be consumed it must be re-transformed to 10 amperes at 200 volts. Generally, alternating current is employed.

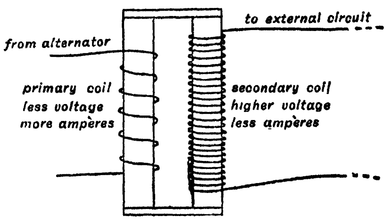


FIG. 268.—THE PRINCIPLE OF A STEP-UP TRANSFORMER.

These changes in voltage and amperage in alternating currents are brought about by means of apparatus called **transformers** (Fig. 268). A transformer is an induction or influence apparatus consisting of two separate coils of insulated wire wound on an iron core which strengthens the magnetic field of the arrangement. One coil is much longer and made of thinner wire than the other, and the relative length of the two coils determines the degree of current transformation. If the voltage is to be increased ten times, then the **secondary coil** must be ten times as long as the other **primary coil** through which the current from the generators is passed. If a current

of 10 amperes at a voltage of 200 is passed through the primary coil, then by electro-magnetic influence a current of one ampere at a voltage of 2000 is generated in the secondary coil. An apparatus of this kind which increases the voltage is called a *step-up* transformer. At the distant place of consumption a *step-down* transformer is employed, the current at 2000 volts being passed through a coil ten times as long as the secondary coil in which an induced current of 10 amperes at 200 volts is again obtained. The *secondary* coil of a transformer is always the one bearing the induced current.

CHAPTER XXXI

SOME RECENT DEVELOPMENTS OF ELECTRICITY

TRANSFORMERS are used for other purposes besides power transmission. An apparatus employed for the production of a higher voltage at the expense of current is a **low frequency transformer** used in many wireless receiving sets. Its mode of operation is similar to that of the larger apparatus used in power stations, and briefly described in the previous chapter. A shorter primary coil is placed against, but separated from, a longer secondary coil, the coil being wound around a soft iron core. In a transformer of good construction this core consists of a number of thin iron plates of laminae, since such an arrangement prevents the occurrence of *eddy currents* which would be formed in a larger continuous piece of iron. The function of the apparatus is to increase the voltage applied to the grid of a valve (see below) attached to the longer secondary coil, by passing the current from the plate of the preceding valve through the primary coil. The transformer is described as of low frequency because its work is concerned with the production of sounds in the loud speaker, and sound waves are of very much lower frequency than are the high frequency, electro-magnetic waves producing electric current in an aerial.

Another transformer of considerable practical value is known as an **induction coil** (Fig. 269).

As in other similar apparatus, there is a short primary coil composed of thick wire surrounded by a very much longer coil of thin wire. The wires are well insulated, and the coils are separated by waxed paper.

The primary coil is wound around a core consisting of a number of soft iron wires which prevent the formation of eddy

currents which would lessen the efficiency of the apparatus, just as local action does in the zinc of a voltaic cell (Chapter XXIX). Since currents are induced in the secondary coil only when a variation occurs in the magnetic field around the core, the battery current flowing along the primary coil is rapidly started and stopped by a make and break arrangement similar to that in an electric bell. An iron hammer is attracted to the magnetised core, and its movement causes a gap near the screw point so that the current is stopped, and the hammer springs back again. Every time the primary current is started an induced current occurs in the secondary coil in the opposite direction, and every

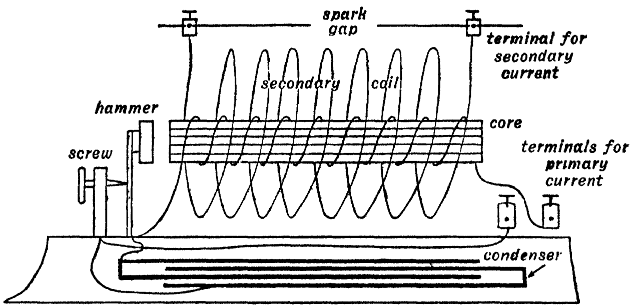


FIG. 269.—DIAGRAM OF THE PARTS OF AN INDUCTION COIL.

time the primary current is stopped an induced current in the secondary coil flows in the same direction as that in the primary.

A very important part of an induction coil is the condenser placed in the base of the instrument. This consists of one set of tinfoil plates alternating with the plates of a similar set, but separated from them by waxed paper. When the hammer is pulled away from the screw the primary current exhibits *inertia*, it does not stop absolutely at once, and is discharged into the condenser, and is then sent back into the primary coil when contact is made again.

By this means the efficiency of the apparatus is greatly improved. Small coils used for medical purposes are sufficiently powerful without a condenser. The voltage or E.M.F. of the secondary coil depends upon its length relative to that of the

primary coil. When the ratio is great, an E.M.F. of thousands of volts is produced, so that a spark discharge occurs across a gap between pieces of metal attached to the ends of the secondary coil. The insulation of the air particles in the spark gap breaks down, and the electric discharge zigzags or ramifies along the path of least resistance. A flash of lightning is a gigantic spark which is always forked or ramifying (Fig 285); so-called sheet or summer lightning being the reflection of a branching discharge taking place below the horizon. The length of spark obtained from an induction coil depends upon the size of the apparatus; the largest ever made was constructed by the electrical engineer Spottiswood, and gave a spark 42 inches long; but for X-rays and other purposes a coil producing a six-inch spark is quite large enough.

RÖNTGEN OR X-RAYS

During the latter half of the nineteenth century, many interesting discoveries were made by **Sir William Crookes** and others concerning the minute particles of which matter and electricity are composed. Whilst experimenting with electric spark discharges passed through rarefied gases contained in glass tubes, **Röntgen,** in 1895, discovered that certain radiations or wave-motions proceeding from these tubes possessed the power of penetrating sheets of paper and other objects which do not permit light rays to pass through them.

At ordinary atmospheric pressure, air and other gases are non-conductors of electricity, and it requires a very high voltage to break down the air resistance so that a spark or electric discharge passes. When the air is much rarefied and the pressure reduced to a very small fraction of its normal value, the electric discharge, consisting of a stream of minute particles of electricity or **electrons,** passes much more easily and the gas itself becomes luminous. Different gases show different characteristic colours; thus hydrogen appears red, carbon dioxide pale green, helium and argon bright red, neon, a deeper red, and so on. Tubes containing these gases very much rarefied are known as vacuum or discharge tubes; neon tubes in particular are used commercially for illuminated signs.

If the degree of exhaustion of the gas is increased further, the luminosity disappears, but the stream of electrons continues, and the glass itself becomes luminous. Since electrons are particles of so-called negative electricity, they are projected at a great speed from the cathode or negative wire of the tube, and for this reason the stream of electrons is known as the **cathode rays** (Fig. 376). If the stream of electrons strikes a target or piece of metal, the impact results in the production of electromagnetic waves of exceedingly short wave length ranging from 0·0004 to 0·8 of one millionth of an inch, too small to affect vision, but still capable of affecting a photographic plate. These extremely small waves are popularly known as **X-rays**, and are capable of penetrating many solid materials. Some substances are more transparent to these rays than others; thus the fleshy portions of the hand are more transparent than the bones, consequently the bones cast a deeper shadow than the flesh does in an X-ray photograph or radiograph.

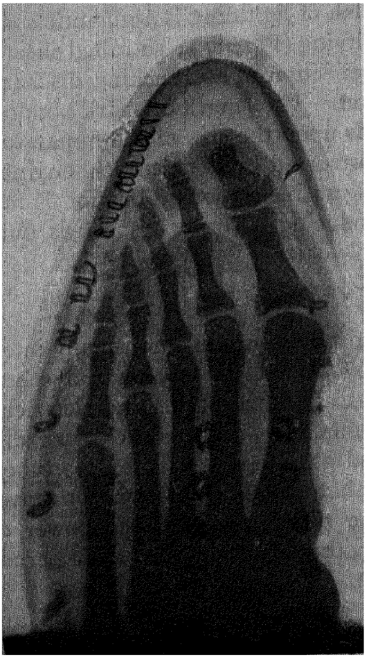


FIG. 270.—X-RAY OF FOOT INSIDE A BOOT.
(By courtesy of Savoy Taylors' Guild.)

An X-ray tube (Fig. 271) is a globe having projecting parts carrying the electrodes, and containing air at a very high degree of rarefaction. The negative electrode or cathode is a curved piece of metal projecting the electrons so that they hit a target. The target itself is composed of tungsten and is called the **anticathode**. From this the X-rays proceed, though the glass

itself becomes luminous or fluorescent with a pale green light. Fluorescent substances are those which become luminous under the influence of X-rays, *barium platinocyanide* exhibiting this in a marked degree. If a piece of cardboard is covered with this substance a sensitive fluorescent screen is obtained. An object, such as the hand, placed in the path of the rays and in front of the screen casts a shadow, and as we have noted, the bones cast a deeper shadow than the flesh. A piece of steel embedded in the flesh casts a shadow deeper still.

A shadow picture is thus formed on the screen, but in surgical work a photograph is generally required. Of course a camera is not necessary, all that is required being a photographic plate wrapped in a paper light-proof covering. The part to be photographed is placed just above the plate and is exposed to the rays for a certain time, then the plate is developed in the usual way. With special apparatus dental surgeons can obtain radiographs of the teeth and gums, thus obtaining valuable information. X-rays are also employed by excise officials for the detection of contraband disguised in parcels, etc. Imitation diamonds can be detected by the fact that genuine diamond is opaque to the rays.

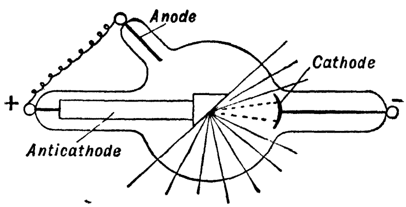


FIG. 271 —AN X-RAY TUBE.

WIRELESS TELEGRAPHY AND TELEPHONY

When an electric spark passes between the ends of a spark gap connected with an induction coil or other apparatus generating a high electromotive force, the discharge is not merely in one direction only; it surges forwards and backwards. In other words the discharge is *oscillatory* in character. Electric oscillations of this kind disturb the ether so that electromagnetic waves proceed in all directions away from the spark gap. The existence of such waves was suggested by **Clerk Maxwell** as early as 1864, and while admitting the great part played by **Marconi,** who made

wireless telegraphy a practical working affair, we must not forget the pioneer work of others who laid the foundations upon which this marvellous modern achievement rests. Nor must we overlook the fact that the reproduction of music in our homes, and the ability to carry on a conversation with persons on the other side of the world without wires is due to the genius of **Dr. J. A. Fleming,** who invented the **thermionic valve,** and to the American, **Dr. Lee de Forest,** who improved it.

Sir Oliver Lodge showed that when an oscillatory discharge or spark passed across a space or air gap in one circuit, another spark jumped across another gap in a separate circuit, placed at a little distance from the first, provided that the second circuit were properly ' in tune ' with the first. The original spark caused a disturbance in the separating medium or ether, and in virtue of this disturbance, electricity was generated by induction in the tuned circuit. Later he discovered means of producing similar effects when a distance of nearly 200 feet separated the two circuits. The famous German scientist, **Hertz,** in 1888, showed that the disturbance occurring in the intervening medium was of the nature of wave motion traversing the ether, consequently these electromagnetic waves are often termed **Hertzian waves.** Marconi discovered means of transmitting and receiving these waves over long distances. He found that by connecting his oscillatory circuit to the earth and by using elevated aerials the waves could be sent more effectively into space. In many of his earlier experiments performed at his home in Pontecchio he employed large pieces of sheet metal as aerials. In 1899 he succeeded in effecting wireless communication between England and France, and the first wireless messages passed between England and America in 1902. Quite recently Marconi has developed the **beam system** of wireless, in which the waves are projected by suitable ' reflectors ' as beams analogous to the beams of light projected by a searchlight. The beam system means less loss of energy and consequently greater carrying power.

Let us consider quite simply and without unnecessary detail how Hertzian waves are sent out and received.

A simple transmitter for sending out discontinuous waves or

spark signals, by which wireless telegraphy by Morse code is possible, consists of an induction coil and a spark gap, to which is attached a tuned aerial (Fig. 272). The tuning device which determines the length of the waves radiated consists of a condenser and an inductance coil, the lower end of which is connected with the earth. A tap key controlling the current flowing along the primary of the induction coil is worked by

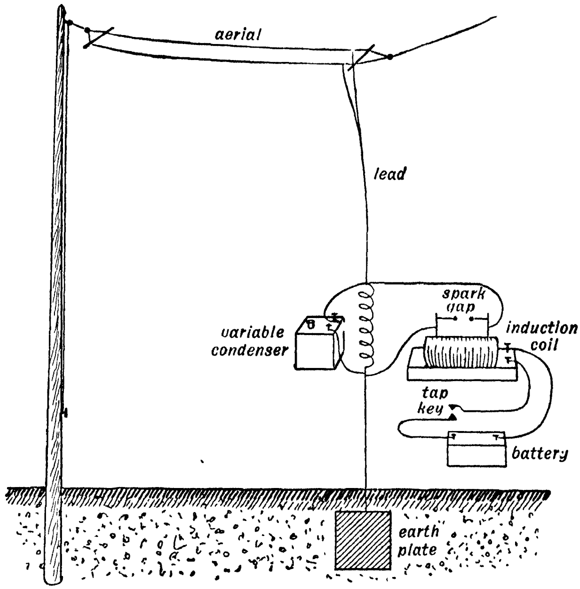


FIG. 272.—A SIMPLE CIRCUIT FOR THE WIRELESS TRANSMISSION OF 'SPARK' SIGNALS.

the operator, who sends out the desired combinations of dots or quick sparks, and dashes or sparks of longer duration. How are the waves radiated by this transmitting apparatus received and converted to sounds in a telephone at any receiving station?

Now, the ether waves, when they impinge upon the tuned aerial of a receiving apparatus, induce electric currents in the aerial, and these currents are oscillating or alternating, they race forwards and backwards along the aerial sytem. Such alter-

nating currents will not work a telephone, hence some **rectifying device,** commonly known as a detector, is necessary to cause currents flowing in one direction only to pass through the telephones or loud speaker. Certain crystalline substances, such as the mineral galena (lead ore), and the artificial product called

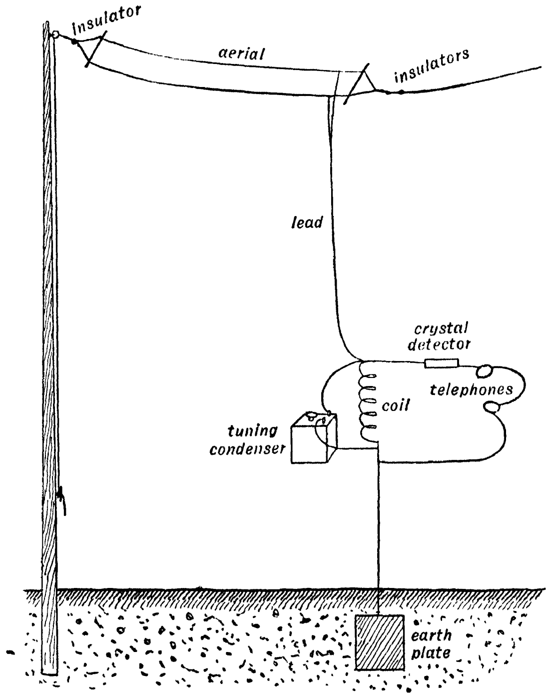


FIG. 273.—A SIMPLE CIRCUIT FOR RECEIVING WIRELESS MESSAGES, MUSIC, ETC.

carborundum, possess the property of allowing currents to pass in one direction only, hence we have crystal receivers, but their range of reception is very limited, merely a few miles; even in the case of high powered stations, such as Rugby (commercial messages, etc.), or Daventry (broadcast programmes), clear reception by a crystal detector cannot be guaranteed at distances greater than 100 miles.

With any kind of receiving set the aerial must be tuned by means of a coil of wire and a condenser, so that it responds properly to the wave-length of the transmitting station.

The range of reception is greatly increased when rectification is performed by a thermionic valve. In order to understand how such a valve operates, we cannot do better than consider first the *two electrode* valve invented by Dr. Fleming in 1904 (Fig. 274). The two electrodes, or parts, consist of a metal **filament** which can be made white hot by a current from a low tension (*i.e.* at small voltage) battery or accumulator, and a cylinder of copper called the **anode** surrounding but not touching the filament. Both parts are enclosed in a glass bulb from which the air has been exhausted; thus the valve is a special kind of electric lamp. By means of wires passing through the glass the anode can be connected with the aerial system, and the filament can be connected to telephones which are also joined to the earth end of the aerial system. When the filament is rendered white hot by the battery current electrons escape from it. In valves of the **dull emitter** type, the filament is coated with thoria and the electrons are thrown off at a lower temperature.

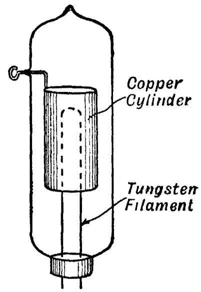


FIG. 274.—A FLEMING TWO-ELECTRODE VALVE.

The anode, being influenced by the alternating currents in the aerial, is at one fraction of a second positive, the next fraction of a second negative, and so on. When the anode is positive, electrons are attracted to it, and a current passes through the telephones, but when the anode is negative, it repels the electrons and no current passes through the telephones. Thus the lamp functions as a valve, permitting currents to pass through the telephones in one direction only, and sounds are possible. This simple receiving arrangement was employed in the early days of wireless transmission. Lee de Forest's three electrode valve is now used in receiving apparatus, though the two electrode valve still performs important work in transmitting stations where a high voltage current from an alternator is converted to a current in one direction. Similarly, such a valve is employed for the

rectification of alternating current for the purpose of charging accumulators as in trickle chargers and battery eliminators.

In the three electrode valve (Fig. 275) a third part, called the **grid,** consisting of a spiral of wire, is placed between the filament and the anode or plate. The anode, which is not connected to the aerial, is kept at a high positive potential by being placed in contact with the positive end of a high tension battery, usually having a voltage of 60 or more. Since the anode is always positive, there is a tendency for electrons to be drawn continually from the filament, but the grid acts as a policeman and regulates the traffic of electrons crossing to the plate. The grid is connected

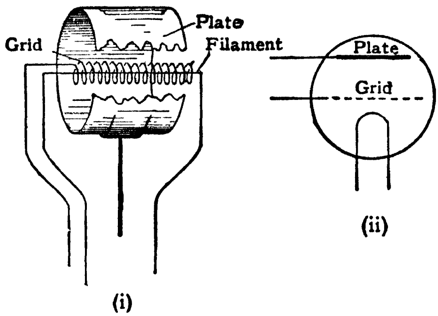


FIG. 275.—THE PARTS OF A THREE-ELECTRODE VALVE USED IN WIRELESS RECEIVERS.

(i) A COMMON ARRANGEMENT OF THE PARTS. (ii) A CONVENTIONAL DIAGRAM REPRESENTING A VALVE IN DIAGRAMS OF WIRELESS CIRCUITS.

to the aerial system and, as it were, receives its orders from the electric impulses surging up and down the aerial. At one moment, while the aerial current is in one direction, the grid is positive and helps in drawing electrons over to the plate, at the next moment, the aerial impulse being in the other direction, the grid becomes negative and prevents electrons from passing (Fig. 276). The grid is really part of the aerial system and partakes of all electrical fluctuations occurring in the aerial, with the result that exactly corresponding fluctuations occur in a one-direction current proceeding from the plate and operating the telephones, so that variations of sound take place. The telephones are connected to the plate of a three electrode valve.

In the case of wireless telephony, which reproduces continuous speech or music, discontinuous waves originating from sparks are of no use. **Continuous ether waves** are necessary, and these are now generally produced by three electrode valves, but sometimes the **arc system**, invented earlier by **Poulsen,** is employed at transmitting stations. The actual mode of producing continuous waves is of too technical a nature to be discussed here.

A wireless broadcasting station generates by electrical means a continuous wave motion of a definite wave length. For example, the waves radiating from the Oxford Street aerial of the London station are 361·4 metres long. For a few minutes preceding the commencement of a programme these **carrier waves** are proceeding through space, but are not subjected in any way to variations due to speech and music. Immediately the announcer speaks the wave form is modified, and these modifications are faithfully reproduced in the loud speaker at home. By what sequence of events is this result achieved? Stated very simply this sequence is as follows:

1. Sounds affect a **microphone** forming part of a circuit bearing electric currents. (2) These currents undergo variations according to variations of the sound influencing the microphone. (3) Such varying currents are superimposed upon the electrical impulses radiating the wireless waves. (4) The carrier waves are thus undergoing continual modification. (5) The currents induced by the carrier waves in a receiver's aerial are correspondingly modified. (6) The plate current of a receiving set undergoes an exactly equivalent series of modifications. (7) The telephones or loud speaker operated by this plate current reproduce sounds exactly similar to those made in front of the microphone at the transmitting station.

In spite of these numerous transformations of energy, the music reproduced is surprisingly free from distortion in a good wireless receiving set.

The actual volume of sound obtained from a loud speaker is considerable though the amount of electrical energy developed in the aerial is small, and the extra energy needed is supplied by batteries. In order to use this additional energy in the necessary way the three electrode thermionic valve is again employed, this

time as an **amplifier.** When a series of electrical impulses are given to the grid of a valve an exactly similar but stronger series of impulses proceed along the wires connected to the plate or anode, hence there is an amplification or magnification of the original impulses. If a valve is used to magnify the impulses of the aerial *before* they are rectified or detected, the valve is described as a high frequency amplifier, but if it is used to magnify the impulses *after* rectification the valve is known as a low frequency amplifier. The terms high and low refer to the

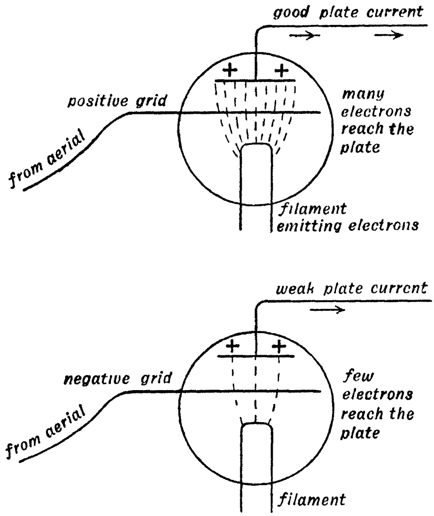


FIG. 276.—EXPLANATION OF THE ACTION OF A THREE-ELECTRODE VALVE AS A DETECTOR.

great difference in frequency between the aerial currents and the sounds issuing from a loud speaker, as explained at the commencement of this chapter. Space does not permit any description of the various modes of joining or 'coupling' valves together; for such information a student must refer to the various journals dealing adequately with the construction of wireless sets.

Wireless waves may also be used for **direction finding** either at sea or on land. A frame aerial or rectangular hoop of wire receives wireless impulses best, and consequently gives loudest

signals, when it is arranged in a direction end on (*i.e.* not broadside) to the direction in which the ether waves are travelling. Thus a ship is able to take its bearings in relation to the position of a land station sending out wireless waves.

Other developments which are in progress but as yet far from being complete are **telephotography** and **television.** In the former, pictures of events are sent by wireless and reproduced in the press, the time taken in the operation being only a few minutes. The aim of television is to enable people to see events happening at a distance, just as the telephone enables one to hear a voice or music at a distance. Though, however, it is possible now to broadcast from a central station the face of a performer so that it can be seen as a blurred image in suitable receiving apparatus, there is no immediate possibility of people being able to see one another while they speak.

CHAPTER XXXII

STATIC ELECTRICITY

As early as 600 B.C. it was known that a piece of amber rubbed by wool possessed the power of attracting small fragments of straw, etc., and the word electricity is derived from **electron,** the Greek word meaning amber. A piece of amber excited in this way is said to be electrified, the electricity developed making itself apparent by its power of attraction over small bodies. Sealing-wax rubbed by flannel, glass rubbed by silk, cat's skin stroked by a dry hand, and many other substances, exhibit similar properties. It must be noted that both the substance rubbed and the rubbing material are electrified, though it is not always easy to demonstrate this fact. When you stroke a cat's back in dry frosty weather small sparks are visible, a crackling sound may be heard, and the cat's hairs stand up straight, because any hair endeavours to get away from others near it. Your hand is also electrified, but the electricity produced on it immediately escapes to the earth through your body. If you were to stand upon a slab of thick dry glass, however, your hand would exhibit the power of attraction over light bodies, pieces of paper for example, because the glass is an insulator preventing the escape of electricity to the earth. The cat's fur itself is an insulator, hence its electrification becomes apparent. Your body, pieces of metal, and water are all conductors which permit electricity to escape. Because moisture is a conductor, experiments connected with this kind of electricity can be performed only when the apparatus employed is quite dry.

The electricity produced on glass rubbed by silk does not behave in exactly the same way as the electricity produced on sealing-wax rubbed by flannel. About 200 years ago it was

believed that there were two distinct kinds of electricity, and **Benjamin Franklin,** whose kite experiments demonstrated that lightning is a form of electric discharge, proposed the terms **positive** and **negative** for the two kinds. We still use these terms, though modern researches have considerably modified our views about the nature of electricity. It is quite easy to show that electricity behaves as if there were two distinct kinds. If a small piece of dried elder pith is suitably suspended by a piece of silk thread, we have a very simple kind of **electroscope** (Fig. 277). Now, if glass rubbed by silk is brought near, but not allowed to touch, the pith ball, the latter is attracted towards the glass. If the ball is now made to touch the glass, it receives a small charge of the electricity and is repelled or pushed away.

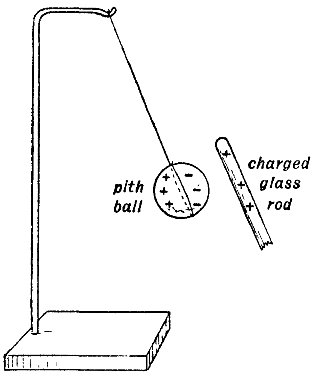


FIG. 277.—THE PITH BALL ELECTROSCOPE.

Electric charges of the same kind repel each other, and this is similar to the repulsion between magnetic poles of the same kind. The pith ball now holds a small charge of so-called positive electricity, and if a piece of sealing-wax rubbed by flannel is brought near the pith ball, the latter is attracted by the electricity on the wax. The electricity on glass repels the charged ball, that on wax attracts it; from these facts we infer that the electricity on the wax is of the other kind, and we call it negative.

Evidently a *positive charge exerts a mutual force of attraction with a negative charge.*

The positive electricity on the pith ball may be discharged to earth by momentary contact with the hand, and then the ball can receive a charge of negative electricity by contact with the excited sealing-wax. As soon as it receives this negative charge it is repelled by the wax, thus verifying the rule that like charges, whether both positive or both negative, exert a force of repulsion. Once a pith ball or other form of electroscope is given a known

charge of electricity, it can be used to determine the sort of electricity on any electrically exerted substance.

An interesting case is afforded by two pieces of glass of similar composition, but one rubbed with cat's skin, the other with silk. It will be found that the first piece of glass will be electrified negatively, the second piece positively, thus showing that the nature of the rubbing material is a factor in the case.

Electricity of this nature was formerly called **frictional**, because of the rubbing process, but in reality contact of dissimilar substances is the essential condition, the friction merely ensuring a good contact. Since electricity produced in the way we have just considered does not flow as a current but remains *standing* on the charged material, a very suitable name is **static** electricity, and this term is now generally employed.

ATOMS AND ELECTRONS

Since electricity is rapidly transferred from one body to another in contact with it, and since it flows along wires at a great speed, it was for a long time believed to be in the nature of a fluid, but recent investigation on the nature of the atoms composing various substances have shown that it consists of minute particles called **electrons**, or more correctly, the so-called *negative* electricity consists of electrons.

(i) The Hydrogen Atom **(ii) The Helium Atom**

FIG. 278.—ATOMIC STRUCTURES.
PROTONS SHADED, ELECTRONS UNSHADED.

It was formerly believed that an atom was the smallest conceivable particle of matter and could not be composed of still smaller units. But we have now good reasons for believing that any atom is not a simple indivisible structure, but is composed of a nucleus consisting of one or more **protons** and electrons surrounded by a space in which one or more electrons or particles of negative electricity revolve at great speed (Fig. 278). An atom is

thus like an exceedingly small solar system, the nucleus to some extent corresponding to the sun, and the revolving electrons corresponding to the planets. The simplest atom is that of hydrogen and consists of a single proton forming the nucleus around which a single electron is revolving. Other forms of matter consist of atoms more complicated than this, there being in some cases quite a large number of revolving electrons as well as some electrons helping the protons to build a complicated nucleus.

A more detailed account of atomic structure is given in a later chapter dealing with radium and radioactivity, but it must be observed here that in the process called electrification some of the electrons are torn away from atoms so that the remainder, being deficient in negative electricity, appears to be charged positively, and in its endeavour to capture electrons it exerts an attracting force for negative electricity. The escaped electrons give a charge of so-called negative electricity to the body to which they become attached.

Thus when sealing-wax is rubbed with flannel, electrons are torn off the atoms in the flannel (which appears positively charged) and give a negative electrification to the wax. According to this view, a current of electricity consists of an extremely rapid motion of free electrons along a wire or other conductor.

ELECTROSTATIC INDUCTION

A redistribution of electrons can be accomplished by influence without contact. Just as a piece of steel or iron can be magnetised by induction (see Chapter XXVII), so an insulated body can be electrified by electrostatic induction. The pith ball of the simple electroscope is attracted towards the electrically charged glass rod because electrons are attracted to the side of the ball facing the glass. In the same way a large metal ball insulated by a glass support can be influenced by a charge of electricity placed near, but not in contact with it (Fig. 279). If the inducing charge is of the so-called positive kind, then the electrons are attracted to the side of the ball facing the charge and the further side of the ball is deficient in electrons. Now if *any* part

of the ball is momentarily touched, or earthed, while the inducing charge still exerts its influence, additional electrons are drawn from the earth, which acts as an inexhaustible reservoir. If the connection to earth is just removed, and then the inducing charge is taken away, the ball is left with an excess of electrons and is said to possess a negative charge of electricity. The metal ball is thus charged by induction, and the inducing charge is not in any way reduced quantitatively. Should the inducing charge be of the negative kind, then electrons are repelled to the further side of the ball and will escape to earth when the ball is momentarily touched while the inducing charge is still present, and on the removal of this influence, the ball will be deficient in electrons, or possesses a so-called positive charge.

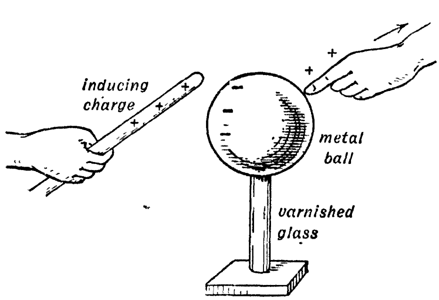


FIG. 279.—CHARGING A CONDUCTOR BY MEANS OF ELECTROSTATIC INDUCTION.

One or two facts concerning this mode of electrification must be observed. Any number of insulated bodies can be charged by the influence of a single inducing charge, the work done in bringing the charging body near the various objects, one at a time, providing the energy needed. Each time, the total induced charge is equal to the inducing charge, though it is difficult to obtain all of the induced electricity upon one object, since the influence is exerted in the electric field which extends in all directions around the inducing charge.

The nearest approach to obtaining all the induced electricity on one body occurs when a charged ball is lowered by a silk thread into a tall insulated metal can with a narrow mouth.

The nature of the non-conducting medium separating the inducing charge from the object under influence is a very important factor of induction. Dry air is taken as the standard medium, and it is found that other media, such as rubber, glass, mica, and porcelain exhibit various capacities for transmitting

induction force. Hence we have specific inductive capacity, that of air being 1, that of flint glass 7·4, and so on. In all cases the intervening medium is strained by the inducing charge, and it is largely by reason of this strain that induction takes place. When a spark occurs, the medium (usually air) breaks down, but heals itself, as it were, after the discharge has taken place.

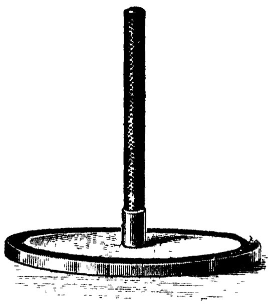


FIG. 280.—AN ELECTROPHORUS.

A simple piece of apparatus employed for obtaining charges of electricity by induction is the **electrophorus** (Fig. 280). This consists of a circular plate of vulcanite, which is electrified by being rubbed with cat's skin. Negative electricity generated on the surface of the plate acts inductively upon a circular metallic disc placed upon it, and held by means of an insulating glass handle. The metallic disc does not become charged by contact, except perhaps at a few points, because a thin layer of air separates most of it from the vulcanite plate below.

Electrons are repelled to the top surface of the metal, and on touching it momentarily with the finger they escape to earth. Then upon lifting the metallic plate it is charged positively, since

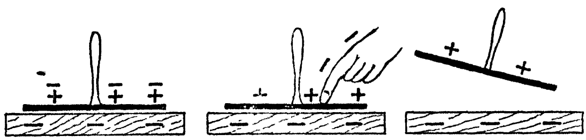


FIG. 281.—THE MODE OF WORKING OF THE ELECTROPHORUS.

there is a deficiency of electrons. The operation can be repeated several times and the electric charges given to other bodies by contact. The electrophorus is more suitable for demonstration purposes than for anything of a more practical nature.

A larger and more useful induction apparatus capable of giving considerable charges of electricity is the **Wimshurst machine,** which is sometimes employed for the generation of X-rays when

an induction coil is not available (Fig. 282). Two varnished circular glass plates each carry a large number of metallic sectors placed radially. As the two plates are caused to rotate in opposite directions these sectors come in contact with metallic brushes placed at certain positions. Though these brushes in the first case give by friction a small initial charge to the sectors, their main function is to touch any sector at the moment it is opposite an inducing charge on a sector on the other plate. Thus the brushes act in the same way as a finger which touches the metallic disc of the electrophorus. At two other positions the charged sectors come in front of metallic combs or sets of points placed horizontally. Now, an electric charge escapes from points, consequently electricity proceeds from the points to the sectors producing electric equilibrium there, but leaving an excess of electricity on the metallic objects attached to the combs.

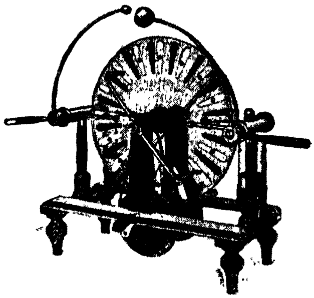


FIG. 282.—A WIMSHURST MACHINE.

These collecting objects which store the electricity until a spark discharge occurs are known as **Leyden jars,** from the fact that they were first used at Leyden in Holland.

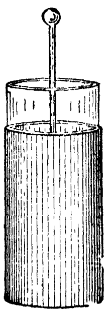


FIG. 283.
A LEYDEN JAR.

CONDENSERS

A Leyden jar (Fig. 283) is a good example of a **condenser** and is composed of glass well varnished with shellac and partly covered both outside and inside with coatings of tinfoil. The inner coating is in contact with a piece of chain attached to a brass rod terminating in a knob touching the metallic frame supporting the combs of the Wimshurst machine. Thus by contact the inner coating is charged with electricity, and the quantity it can hold depends largely upon the size of the Leyden

jar. But the capacity of the condenser is determined by another factor in addition to size. The outer coating of the jar is connected with the earth, so that electricity obtained from the earth exerts an attracting influence upon the inner coating, which is thus enabled to hold more electricity than it would do otherwise.

Any condenser consists of two separated plates, or sets of plates, one being connected to earth or other body functioning as a reservoir of electricity. In wireless circuits condensers play a very important part, both those having a fixed or invariable capacity and others in which the capacity can be varied by means of a set of movable plates which are interleaved with and move between a set of fixed plates.

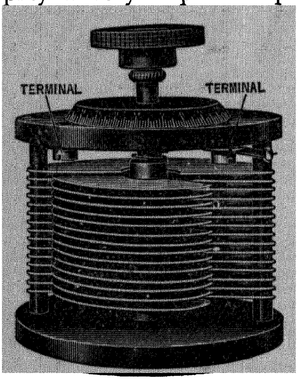


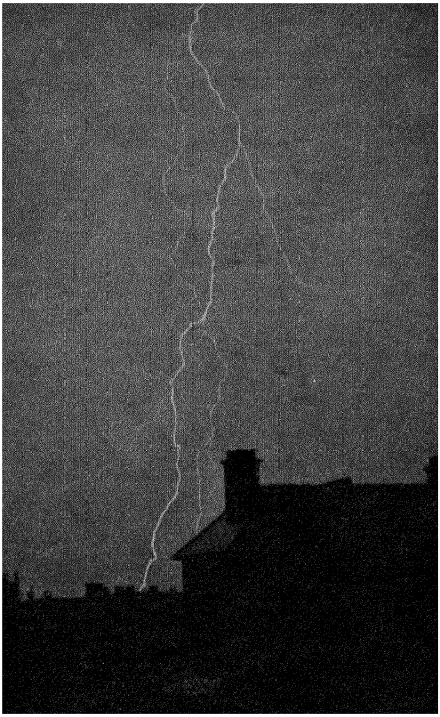
FIG. 284.—A VARIABLE CONDENSER.

So far as tuning a wireless aerial to a given wave-length is concerned, an increase of capacity obtained by a variable condenser (Fig. 284) is equivalent to the use of a larger inductance coil. It is very inconvenient to make slight alterations in the length of a coil, hence a coil of suitable length is used in conjunction with a variable condenser. Most wireless receiving sets contain several small fixed condensers which function in rather a different way. The ordinary one-way current from the low tension battery cannot pass through such a condenser, but high frequency oscillating impulses can pass by means of influence. Variations in the electrical condition of one plate produce similar variations in the other plate though a non-conducting substance, usually mica, separates them. For this reason such a fixed condenser is often described as a by-pass for oscillating high frequency currents.

THUNDERSTORMS

Large quantities of static electricity collect in clouds owing to disturbances of the atmosphere, particularly the rapid move-

ment of air columns due to sudden changes in temperature. Suppose that a large cloud becomes charged negatively, then it exerts a powerful inductive influence upon other clouds and upon the surface of the ground below. Electrons are repelled,



(*Photo. Dr. W. J. S. Lockyer.*)

FIG. 285.—LIGHTNING.

THE ELECTRIC DISCHARGE RAMIFIES IN TAKING THE PATH OF LEAST RESISTANCE.

so that the other clouds and ground become charged positively. Objects on the ground also share in this electrification, and though discharge commonly occurs between clouds, it sometimes happens that a flash of lightning or large spark passes between a tall object, say a tree, and a charged cloud. When this

discharge happens, the ground and objects regain electrical equilibrium instantly, and it is this sudden alteration in electrical condition that is dangerous to people or cattle situated near the tree. The change takes place so suddenly that fatal results often occur, and since the disaster is due to the return of normal conditions, the phenomenon is known as return shock. The highest objects reach nearest the clouds and are naturally the most likely to be struck, hence the safest places during a thunderstorm are those near the ground and away from trees, etc. Also, water in ponds and ditches should be avoided.

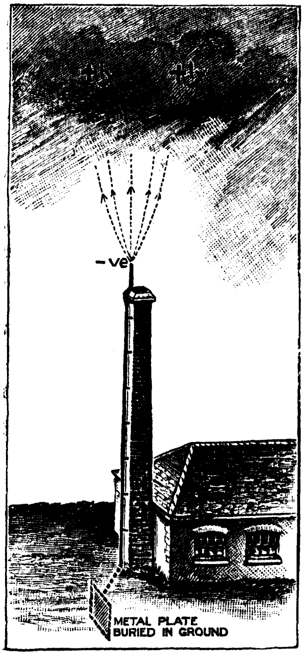


FIG. 286.

A LIGHTNING CONDUCTOR DISCHARGES ELECTRICITY OF THE OPPOSITE KIND TO THAT IN A CLOUD, THUS TENDING TO NEUTRALISE IT.

Since an electric charge always gets as near to the inductive influence (the cloud) as possible, a particularly safe place is any dry hollow in the ground where there are no trees. If it were not for the fact that a building may be struck and persons injured by falling masonry, etc., the inside of a house would be a perfectly safe place. Faraday demonstrated by placing himself with delicate electroscopes inside a large metallic box, which was then strongly electrified, that when the disturbing influence is outside, electrical charges always collect on the outside of a body. Neither he nor his instruments experienced the slightest electrical disturbance when within the charged chamber.

Electricity accumulates near points, so that the charge becomes too great to remain and there is a leakage. The air particles near the points become charged, are repelled, more particles take their places and the process is continued. In this way there is a

stream of electricity escaping, a fact which explains the use of a lightning conductor, which consists of several pointed metallic spikes connected by a thick metal band with the earth (Fig. 286). The conductors are placed on high chimneys, churches, etc., and in discharging electricity of the opposite kind to that in a cloud, they tend to neutralise it and so often prevent lightning from taking place. When a thunderstorm occurs in spite of lightning conductors it is because the latter are not numerous enough to cope with the situation, and discharges frequently occur between clouds too high to be influenced by conductors.

Air normally offers a very great resistance to the passage of electricity, consequently it requires an enormous difference of potential, probably millions of volts, to cause a flash of lightning. As in the case of smaller spark discharges obtained from a Wimshurst machine or an induction coil, the discharge is oscillating and zigzags about in taking the path of least resistance.

QUESTIONS AND EXERCISES

[*Questions marked* C.S.C. *are taken from papers set at Civil Service Commission Examinations, with the permission of the Controller of H.M. Stationery Office* ; *and those marked* O. and C. *are from Examinations of the Oxford and Cambridge Schools Examination Board.*]

PART II.

MECHANICS, HYDROSTATICS, ETC.

1. When a body is weighed on an ordinary balance at different points on the earth's surface its weight appears to remain constant, but if a spring balance be used the weight varies from place to place. Explain this. [O. and C.]

2. Explain the formation of marine tides.

3. Describe some mechanism employed for using the energy of falling water.

4. How is the period of swing of a pendulum related to its weight, its length, and the amplitude of the swing ?

5. What is meant by acceleration due to gravity ? Mention some practical consequences of such acceleration.

6. Explain why a man leans forward when climbing a steep hill.

7. How would you determine the centre of gravity of an iron hoop made by joining together two semicircles, one thicker than the other ?

8. What is the meaning of the terms velocity, mass, force, work, energy, inertia ?

9. What is meant by the *velocity ratio*, *mechanical advantage*, and *efficiency* of a machine. [O. and C.]

10. Explain the action of a ' Jack ' in lifting the wheel of a motor-car. [O. and C.]

11. Explain the principle of a lever, and describe the action of (*a*) a pair of scissors, (*b*) old fashioned coal tongs, (*c*) nut crackers.

12. What is meant by momentum ? Describe appliances which make use of momentum.

13. Describe some form of pulley employed by a builder or engineer.

14. Explain carefully the distinction between *mass* and *weight*. Two children whose weights are respectively 56 and 70 lb. are playing

on a see-saw. If the lighter child is 5 feet from the balancing point where should the other be placed ? [O. and C.]

15. A man can pump 25 gallons of water per minute to a height of 16 feet. How many foot-pounds of work does he do in an hour ?

16. What is the difference between kinetic energy and potential energy ?

17. Define work, and describe an experiment to prove that a falling ball is capable of doing work.

18. What is the mechanical advantage of a lever the load arm of which is 30 cm. long and the effort arm 135 cm. long ?

19. Give in a few words the principle of the screw.

20. When a glass capillary tube is put into water it is found that the water stands at a higher level in the tube than it does in the containing vessel. Discuss this, and describe some other phenomena which are due to the same cause. [O. and C.]

21. Explain why salt or sugar dissolves in water.

22. What is meant by *diffusion* ? Mention some practical consequences of diffusion in liquids and gases.

23. A piece of steel is highly elastic, but a piece of rubber is not so elastic. Explain these statements.

24. What property in particular is possessed by liquids and not by solids ? And what character has a gas which neither liquids nor solids possess ?

25. Explain the nature of the forces which mould a drop of water hanging from a glass rod.

26. Explain why a ship made of iron will float in water though iron itself is heavier, bulk for bulk, than water.

27. 1 c.c. of lead (sp. gr., 11·4) and 21 c.c. of wood (sp. gr., 0·5) are fixed together. Show whether they will float or sink in water.

28. What is the Plimsoll line ? Explain the value of this line in navigation.

29. State the principle of Archimedes, and show how it applies to a solid floating in a liquid. [C.S.C.]

30. What instrument is employed to determine the specific gravity of acid in an accumulator, and how does it operate ?

31. Explain the principle of the hydraulic press.

32. How would you determine the specific gravity of a piece of iron ?

33. State Boyle's Law, and describe some form of apparatus employed to verify the law.

34. Describe a Fortin's barometer, and explain how it measures the pressure of the air.

35. Make a sketch showing how a common pump works. Often when a pump fails to draw, a bucketful of water poured into it will start it working ; how do you explain this ? [C.S.C.]

36. How is the pressure of the atmosphere measured? What difference would you expect to find between the pressure at the foot of a mountain and that at its summit? [O. and C.]

37. 'An anti-cyclone is stationary over the British Isles.' Explain this statement, and describe the weather experienced at the time.

38. Describe some mechanism in which ordinary atmospheric pressure is used to operate it.

39. What is a siphon? Explain its action.

40. Describe the action of the vacuum brake used on railway carriages.

HEAT.

1. When most bodies are heated they expand. Give examples in which this expansion is (*a*) utilized, (*b*) counteracted. [O. and C.]

2. Explain the construction and mode of working of a mercurial thermometer.

3. Explain as fully as you can what is meant by (*a*) the temperature of a body and (*b*) the quantity of heat it contains. How many calories will be given out by a block of copper weighing 140 grams in cooling from 99° C. to 14° C. (Specific heat of copper = 0·1.) [O. and C.]

4. Define each of the following: British Thermal Unit, calorie, large calorie.

5. Why are thermometer tubes usually of very fine bore, and why are they provided with bulbs?

6. Convert the following into temperatures on the Centigrade scale: 71° F., 0° F., −40° F.

7. What is meant by the coefficient of linear expansion? If the coefficient of linear expansion of copper is 0·0000168 find the length of a copper rod at 200° C. if it measures 2 metres at 0° C.

8. 15 litres of air measured at 27° C. are cooled to 7° C. By how much will the volume diminish?

9. The pendulum of a clock varies slightly in length with changes of temperature. Describe devices by which such changes in length may be counteracted.

10. What is Charles's Law? Explain how the pressure of a gas conforms to this law when the volume is constant.

11. Outline briefly the transformations of energy which occur when a steam engine is being driven by a coal-fired boiler. [O. and C.]

12. Give some account of the action of a motor car engine. [O. and C.]

13. Heat is now regarded as a form of energy. What evidence led to this view? Give a brief account of any one of Joule's experiments that helped to establish the relation between the foot-pound and the thermal unit. [C.S.C.]

14. Explain the action of the Diesel oil engine.

15. Give a description of the steam turbine invented by Sir Charles Parsons.

16. What is meant by 'Otto cycle'? Describe an engine operated by the explosion of a mixture of coal gas and air.

17. Give a brief account of the history of the steam engine.

18. Give an account of a circulating hot water system as used in a small house. [C.S.C.]

19. What is meant by 'ventilation,' and how is it obtained in (*a*) an ordinary living-room, (*b*) a coal mine. [C.S.C.]

20. By what different means may heat be transferred from one body to another? Give examples of each method. [O. and C.]

21. Describe the influence of clothing on bodily temperature.

22. Give an account of the permanent winds of the world, their cause and distribution.

23. Explain the action of an ordinary vacuum flask.

24. What is meant by 'latent heat'? How much ice will melt in 100 grams of water initially at 16° C.?

25. Explain the formation of dew, frost, clouds, and fog.

26. Describe the use of liquid ammonia for purposes of refrigeration. The latent heat of vaporization of ammonia is 340 calories per gram. Explain what this means. How many grams of ice at 0° C. can be made from water at 12° C. by the vaporization of 200 grams of liquid ammonia? The latent heat of fusion of ice is 80 calories per gram. [C.S.C.]

27. The rate at which wet clothes become dry when they are hung up in air depends both upon the condition of the air and upon the nature of the material. Explain this statement. [C.S.C.]

28. Describe the effects produced by heating (*a*) a gas, (*b*) a liquid, (*c*) a solid. [O. and C.]

29. Why does a muddy road dry better on a windy and warm day than on a quiet and damp day?

30. Describe a simple form of hygrometer, and explain what measurement is made with it.

LIGHT.

1. Describe a simple experiment devised to show that light travels in straight lines.

2. What is meant by 'umbra' and 'penumbra'? Illustrate your answer by means of sketches.

3. How do you account for the blue colour of the sky and the green colour of a leaf? [C.S.C.]

4. Describe the method you would use to produce a spectrum by means of a prism. How is a rainbow produced in the sky? [O. and C.]

5. Explain what is meant by wave motion, and illustrate your answer by reference to the transmission of light and sound. [O. and C.]

6. Why is it difficult to match coloured fabrics accurately by artificial light ?

7. Explain how the brilliant colours seen in the sky during a vivid sunset are produced.

8. Describe some form of photometer, and explain how you would use it to compare the candle power of two sources of light.

9. Explain the law of inverse squares in connection with the intensity of light.

10. How do different decorative colour schemes for rooms influence the illumination obtained in such rooms ?

11. What is a foot-candle ? Explain the principle of a light meter.

12. Distinguish between glare and diffused light.

13. Describe briefly the different kinds of light installations suitable for country houses beyond the reach of gas and electricity.

14. Explain clearly how it is that an image is produced by reflection at a plane mirror. How is it that the image of the surrounding objects formed by reflection at the surface of a lake appear upside down ? [C S.C.]

15. The driver of a motor car is supplied with a convex mirror in order that he may see the roadway behind him. Explain how it is that he is able to do this.

16. Describe a simple periscope employed for obtaining a view of the country on the other side of a wall or trench.

17. Explain carefully why all objects used as mirrors have very smooth surfaces.

18. Calculate the distance and size of the image of an object placed 12 cm. in front of a concave mirror of focal length 9 cm.

19. Draw diagrams to illustrate the formation, in a concave mirror, of (*a*) a real image, (*b*) a virtual image. Explain the structure of a motor head lamp. [O. and C.]

20. Draw a diagram to illustrate the passage of light through a simple astronomical telescope. What addition must be made to such a telescope for terrestrial uses ? [O. and C.]

21. What kind of lens would you use for a magnifying glass ? Draw a diagram to explain its action. On what does its magnifying power depend ? [O. and C.]

22. Describe the construction and mode of action of the human eye. To what is short sight due ? [O. and C.]

23. Draw diagrams to show the apparent position of a point on the bottom of a river (*a*) when one is looking straight down upon it, (*b*) when one is looking at it from a distance. [C.S.C.]

24. An object is placed 20 cm. from a convex lens and an inverted image is formed 4 times as large as the object. Find the focal length of the lens.

SOUND.

1. How is sound propagated ? Is the velocity of sound in air constant ?

2. What is a hydrophone, and for what purpose is it used ?

3. Explain what is meant by longitudinal wave motion.

4. What is the difference between a musical note and a noise ?

5. Give some account of the different ways in which a musical note can be produced, and explain how its pitch can be varied. [O. and C.]

6. Explain the formation of echoes. In what ways may an echo be useful ?

7. How is the difference between the pitch, loudness, and quality of two sounds accounted for ? [C.S C.]

8. How can the frequency of a tuning fork be determined ?

9. What is meant by resonance ? Describe some musical instruments the action of which depends upon resonance.

10. What is a sonometer, and for what purposes is it used ?

11. How is sound produced by the human voice and received by the ear ?

12. Explain carefully each of the following : fundamental, harmonic, octave.

13. Describe the different schemes of pitch employed in connection with instrumental music.

14. Explain the action of (*a*) an ordinary organ pipe, (*b*) a reed organ pipe.

MAGNETISM AND ELECTRICITY.

1. If you were given a steel bar, how would you discover whether it was magnetised and which was the N. pole ? How would you magnetise it if it were not already a magnet ? [O. and C.]

2. Explain the action of the magnetic compass. Why should one be careful to see that there is no iron in the neighbourhood of the compass when taking a reading ? [O. and C.]

3. Write down what you know of terrestrial magnetism.

4. Describe with diagrams the working of an electric bell. Why are bells usually worked by a battery and not by the current used for electric light ? [C.S.C.]

5. Explain the principle of a simple form of dynamo, and show how a continuous current may be obtained from it. [C.S.C.]

6. Describe the construction and mode of working of a Bell telephone.

7. What is an alternator, and how may currents be passed from an alternator to an external circuit ?

8. Give an account of the different effects which may be observed

when an electric current is passed (*a*) through a thin copper wire, (*b*) through a solution of copper sulphate between copper electrodes. [O. and C.]

9. When an electric current flows in a suitable circuit it produces heat, magnetic, and chemical effects. Describe experiments by which you would demonstrate the production of these effects. [O. and C.]

10. Describe the construction and mode of working of an arc lamp.

11. State the laws of electrolysis, and give particulars of any electrolytic method for measuring current.

Describe the process by which articles are silver-plated. [C.S.C.]

12. For what purposes other than lighting is an electric arc lamp used ?

13. In what ways is electrolysis useful besides electro-plating ?

14. Write a short account of two forms of battery which may be used for the production of an electric current. [O. and C.]

15. Outline the changes that take place in the charging and discharging of an accumulator, and explain why 'pasted' plates are now commonly employed. What advantages and disadvantages does the accumulator possess as compared with the dry cell ? [C.S C.]

16. What is meant by 'local action' and by 'polarisation'? How are these defects remedied ?

17. Give some account of the pioneer work done by Galvani and Volta.

18. Explain the meaning of the statement that the electric current flows in a circuit.

19. Explain the cause of *Polarisation*, and describe the chief method of preventing it.

20. Describe the parts and mode of working of an accumulator having lead plates.

21. Explain the meaning of the terms voltage, resistance, and current. How are the properties for which these names stand related to one another ?

22. Electric circuits may be connected (*a*) in parallel, (*b*) in series. Explain this. Two similar electric bulbs whose resistances are each 300 ohms are connected (*a*) in parallel, (*b*) in series across 100 volt mains. What will be the current in each case ? [O. and C.]

23. What is the Board of Trade unit of electric power, and how are such units measured in connection with home consumption of electricity ?

24. Explain the construction and mode of working of a simple voltmeter.

25. A certain electric lamp is marked '100 watts, 220 volts.' Explain the significance of these terms. Calculate (*a*) the current taken by the lamp, and (*b*) the resistance of its filament. [C.S.C.]

26. If a 16 C.P. 100-volt lamp consumes 35 watts, what is its resistance and what current does it take ?

27. Explain carefully what is meant by electromotive force. What determines the E.M.F. of a battery, and of a dynamo ?

28. Explain the terms volt, watt, Board of Trade unit A lamp is marked '50 watts'; explain this. What other information would you require to ascertain the current the lamp would take ? [C.S C]

29. Explain the principle of a low frequency transformer. In what ways are transformers of importance in the transmission of electric power ?

30. Explain the mode of generation of X-rays, and the way in which a radiograph is taken.

31. State the general principles in transmitting and receiving wireless waves, and describe in detail any form of crystal *or* valve detector.

Explain why it is required at all. [C S C]

32. Say what you know of the work of Sir Oliver Lodge, Marconi, Fleming, and Hertz in connection with wireless telegraphy and telephony.

33. In what way is the three-electrode valve an improvement on the earlier two-electrode valve ?

34. Explain the processes of charging an insulated metal ball (*a*) by conduction, (*b*) by induction. Illustrate your answer by diagrams. [O. and C.]

35. How can you tell whether the electric charge on a body is positive or negative ?

Explain clearly why it is that in a thunderstorm (*a*) a downfall of rain tends to diminish the danger, (*b*) it is most unwise to hold up an umbrella in open country. [C.S.C.]

36. Describe the construction of an electroscope and an electrophorus. Explain how the latter may be used to charge the former. [C.S.C.]

37. Explain the action of a Leyden jar. In what ways are condensers of practical importance ?

38. State what you know of modern views concerning atoms and electrons.

39. How is lightning produced and how does a lightning conductor work ?

40. Describe a Wimshurst machine.

ANSWERS TO NUMERICAL QUESTIONS.

PHYSICS.

MECHANICS, ETC.

14. 4 feet from balancing point. **15.** 240,000 ft.-lb. **18.** 4·5.

HEAT.

3. 1190. **6.** 21°·7 C.; −17°·8 C.; −40° C. **7.** 2·0066 m.
8. 1 litre. **24.** 20 gm. **26.** 739 approx.

LIGHT.

18. 36 cm. in front of mirror, and the image is three times as long as the object. **24.** −16 cm.

ELECTRICITY.

22. (*a*) $\frac{2}{3}$ amp.; (*b*) $\frac{1}{6}$ amp. **25.** $\frac{5}{11}$ amp.; 484 ohms.
26. 285·7 ohms; 0·35 amp.

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